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EIGHTH SESSION

BERNE : JULY, 1910

PROCEEDINGS

VOLUME II

INTERNATIONAL
RAILWAY CONGRESS
ASSOCIATION

EIGHTH SESSION

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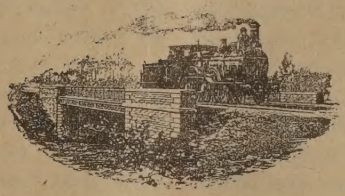

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2ND SECTION — LOCOMOTIVES AND ROLLING STOCK

OPENING MEETING

4 July 1910, 5 p. m.

PROVISIONAL PRESIDENT, MR. BEAUGEY,
MEMBER OF THE PERMANENT COMMISSION OF THE CONGRESS.

The President. (In French.) — Gentlemen, the Permanent Commission has entrusted me with the organization of the meetings of this section (2nd section).

Gentlemen, I will not assume the attitude of an old president or of a president of a parliamentary assembly, and I have neither advice nor instructions to give to you; I would, moreover, not allow myself to give you any, for Mr. Weissenbruch, our distinguished general secretary, has just lately given excellent definitions of the functions both of the Congress and of the different sections forming it.

I will limit myself to the statement that we expect much from the discussions or rather from the exchanges of opinion which will take place between you. Even if, as Mr. Weissenbruch has reminded us, the Congress does not succeed in drawing up any very definite conclusions — it is rarely possible to agree to such conclusions — yet the information which is contained in the very complete reports which have been drawn up, and the opinions which you will exchange, concerning the questions which are of more particular interest to you, and to which the reports have drawn your attention, will be very useful to us.

It cannot in fact be denied that any one who becomes a director or a manager of a system often has to face difficult questions. From the very nature of things, he ceases to some extent to be a technician. That may be an advantage in certain cases and it is perhaps well not to remain a technician to the end, for I think that it may be disadvantageous for a director or a manager himself to work out the solution of the questions he has to deal with; that may even be very dangerous. It is, however, necessary, and it suffices, if he remains technician enough to be able to form an opinion about the questions he has to decide and not to be swayed by any feelings he has retained.

Gentlemen, you will have to investigate a certain number of very interesting and very important questions, which are among those which at present occupy all our minds. I hope that your discussions will contribute towards our enlightenment.

Gentlemen, you now have to appoint your bureau. The Permanent Commis-

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sion proposes that you should appoint as your president Mr. Gerstner, State councillor, delegate of the administration of the Austrian State Railway. (*Applause.*) I am pleased to find that your applause shows that you approve the proposal made by the Commission.

I also propose, on behalf of the Permanent Commission, that you should appoint :

1° As vice-presidents, Mr. Busse, director, rolling stock and locomotive superintendent of the Danish State Railway; Mr. Flury, vice-president of the general administration of the Swiss Federal Railway; Mr. Ernest Gerard, general secretary of the ministry of railways, posts and telegraphs of Belgium, and Mr. Steinbiss, member of the council of the central administration of the Prussian State Railway;

2° As principal secretaries, Mr. Antochine, member of the technical council of the ministry of ways of communication of Russia; Mr. Mazen, engineer of the electrical services of the French State Railway, and Mr. Paul-Dubois, chief rolling stock and locomotive engineer of the Orleans Railway.

If no objection is raised, I declare these proposals adopted. All I now have to do, gentlemen, is to vacate the chair, which will be occupied by Mr. Gerstner, who will preside over your labours. (*Applause.*)

(Mr. Beaugey then vacated the chair, which was thereupon taken by Mr. Gerstner.)

Mr. Gerstner. (In French.) — Gentlemen, I can only thank Mr. Beaugey for the very friendly words he has just uttered and express to you my gratitude for the honour you have bestowed on me in asking me to preside over your labours. I venture to rely upon your cordial assistance and I promise to do my best to carry out my duties properly. (*Applause.*)

— The section, on the proposal of the president, then completed its bureau and drew up provisional agenda.

SECTION II : LOCOMOTIVES AND ROLLING STOCK

[621 .131.2 & 625 .246] QUESTION V

THE USE OF STEEL

SPECIAL STEELS

A. *Use of steel in the construction of locomotives and rolling stock; freight and passenger wagons entirely of steel.*

B. *Use of special steel of high resistance in the making of the various parts of locomotives and rolling stock (tires, axles, springs, couplers, boilers, etc.).*

Reporters :

America. — Littera *A.* — Mr. D. F. Crawford, general superintendent of motive power, Pennsylvania Lines West of Pittsburgh.

All countries except America. — Littera *A.* — Mr. Ernest Szlabey, assistant manager of the locomotive and rolling stock department of the Hungarian State Railway.

America. — Littera *B.* — Mr. R. L. Ettenger, consulting mechanical engineer, Southern Railway.

Countries belonging to the "Verein Deutscher Eisenbahn-Verwaltungen". — Littera *B.* — Mr. Otto Hönigsberg, engineer of the Austrian Southern Railway Company.

Great Britain. — Littera *B.* — Mr. Wilson Worsdell, chief mechanical engineer, North Eastern Railway.

Other countries. — Littera *B.* — Mr. Le Blant, engineer in the testing department and in the experimental workshop of the French Eastern Railway Company.

QUESTION V

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Report No. 2 (littera *A*) (America), by Mr. D. F. Crawford. (See English edition of the *Bulletin* of February, 1910, p. 527.)	V — 21
Report No. 4 (littera *B*) (America), by Mr. R. L. Ettenger. (See English edition of the *Bulletin* of March, 1910, p. 1349.)	V — 101
Report No. 3 (littera *B*) (countries belonging to the *Verein Deutscher Eisenbahn-Verwaltungen*), by Mr. Otto Hönigsberg. (See English edition of the *Bulletin* of April, 1910, p. 1659.)	V — 111
Report No. 6 (littera *B*) (Great Britain), by Mr. Wilson Worsdell. (See English edition of the *Bulletin* of June, 1910, 1st part, p. 2485.)	V — 155
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N. B. — See also the separate issues (in red cover) Nos. 7, 27, 33, 44, 55 and 61.

[621 .131.2 & 625 .246]

REPORT N° 1

(all countries, except America, Great Britain and the countries belonging to the " Verein deutscher Eisenbahn Verwaltungen ")

By Mr. LE BLANT,

ENGINEER IN THE TESTING DEPARTMENT AND IN THE EXPERIMENTAL WORKSHOP OF THE FRENCH EASTERN RAILWAY COMPANY.

I. — General considerations.

Enquiries were addressed on this subject to one hundred and fifty-two companies or railway administration; only twenty-seven replied. Of these, fifteen do not even use special steels experimentally, and twelve use it. Thus the proportion of parties interested in the question is only about 8 per cent.

Taking into considerations the strict wording of the question, it will be seen that a steel, in order to be included, should have both a high resistance and a special chemical composition. In order not to eliminate too many answers, we entered into correspondence with our distinguished colleagues, the reporters for the other countries, and we came to an agreement to give the wording an extended meaning, so as to include within the scope of the question steels, having an ultimate tensile strength of more than 60 kilograms per square millimetre (85,300 lb. per square inch) of original section. The subject of steel for springs, all of which satisfies this condition, has been reserved.

Under these conditions, the sole articles about which we have received answers, and which consequently form the subject matter of the present report, are :

Cranked axles of locomotives;
Tires;
Sundry miscellaneous parts.

*

This short list shows that the use of special steels in railway work is still very limited, as far as the countries we are considering are concerned.

We ourselves think that in the future the conditions under which the metals have to work will become more and more difficult, and that consequently circumstances will compel us to try to obtain durability, together with comparative lightness of the parts, by a more and more extended use of special steels.

II. — Cranked axles of locomotives.

Denmark and Bulgaria.

The Danish State and the Bulgarian State railways use cranked axles of steel containing 5 to 7 per cent of nickel, and having an ultimate tensible strength of 60 kilograms per square millimetre (85,300 lb. per square inch), with an elongation of 18 per cent and a contraction of area of 40 to 45 per cent.

The railways do not mention any results given in practice, as compared with cranked axles of ordinary steel.

Italy.

The Italian State Railway uses cranked axles containing 5 per cent of nickel, and having an ultimate tensile strength of 55 to 70 kilograms per square millimetre (78,200 to 99,600 lb. per square inch), with an elongation of 18 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches) and an elastic limit, in tension, of 38 kilograms per square millimetre (54,000 lb. per square inch). A drop test is also carried out on a notched specimen, and a bending test after quenching.

Various failures in practice have been attributed to too great a nickel content, and this has now been reduced to 5 per cent; this has made the failures cease.

This system has given us no figures as to mileage.

France.

In France, the Midi and the Orleans railways have as yet no working results available. They use chrome-nickel steel quenched and annealed. These steels have an ultimate tensile strength of 60·5 to 75·6 kilograms per square millimetre (86,000 to 107,500 lb. per square inch), with an elongation of 18 to 26 per cent measured on a length of $\sqrt{66 \cdot 678}$ and an elastic limit of 41·5 to 58 8 kilograms per square millimetre (59,000 to 83,600 lb. per square inch). The contraction of area varies from 59 to 62 per cent. The Midi Railway also specifies a drop test on long test pieces. The test piece is subsequently bent in a press till it breaks or is doubled up. The chemical composition varies; the nickel content is 1 to 1·4 per cent and the chromium content 0·25 to 0·35 per cent. On the Midi Railway, 21 per cent

of all the cranked axles are of chrome-nickel steel. Only a few axles are being tried on the Orleans Railway.

The French Eastern Railway is trying some chrome-nickel and nickel axles, hardened and tempered :

1°. The chrome-nickel axles have on the average an ultimate tensile strength of 70 kilograms per square millimetre (99,600 lb. per square inch), with an elongation of 21 per cent measured on a length of $l = 6.67S$. The drop test consists of a blow of 1,500 kilogrammetres (10,850 foot-pounds) given to a bar having a cross-section of 30 × 30 millimetres ($1\ ^{3}/_{16} \times 1\ ^{3}/_{16}$ inch), on supports 160 millimetres ($6\ ^{5}/_{16}$ inches) apart; no crack or fracture must appear;

2° The nickel axles have on the average an ultimate tensible strength of 67·7 kilograms per square millimetre (96,300 lb. per square inch), with an elongation of 18·2 per cent measured on a lenght of $l = 6.67S$. The drop test on test bars is carried out in just the same way as in the case of the nickel-chromium axles.

All the test pieces are cut lengthways.

The chrome-nickel steels contain on an average 1·3 per cent of nickel and 0·2 per cent of chromium.

Other axles of chrome-nickel steel and of manganese-silicon steel are being tried, but at present the mileage is too insignificant to mention.

As working results, we may mention the following mileages run up to 31 December 1908;

473,000 kilometres (293,900 miles), average (from 349,000 to 540,000 [from 216,800 to 335,500 miles]) for the 4-4-0 high-speed locomotives;

530,000 kilometres (329,300 miles), average (from 489,000 to 574,000 [from 303,850 to 356,700 miles]) for the 4-6-0 express or fast-goods locomotives.

But none of the ordinary-steel axles on these two series of locomotives have as yet had to be taken out. The proportion of special-steel axles, as compared with the total number of axles, is 14 per cent in the case of the 4-4-0 locomotives and 3 per cent in that of the 4-6-0 locomotives. Among the latter are included the axles containing 6 per cent of nickel, one of which had to be taken out because a crack formed at the crank pin, after running 287,000 kilometres (178,300 miles).

The future will show whether the Italian practice, of limiting the nickel content to 3 per cent, is sound, as the Italian results and the failure mentioned above would seem to indicate.

The French Northern Railway uses chrome-nickel axles which are hardened and tempered; on the average, the ultimate tensile strength is 67 kilograms per square millimetre (95,300 lb. per square inch), the elongation 19·6 per cent measured on a length of 100 millimetres ($3\ ^{15}/_{16}$ inches), the elastic limit 49 kilograms per square millimetre (69,700 lb. per square inch), and the contraction of area 61 per cent, the test pieces being cut lengthways. There is no official drop test.

Of the cranked axles in use, 8·6 per cent are made of such special steel.

The increase in mileage has varied, with the different locomotives, between 6 and 117 per cent.

The French Northern Railway seems disposed to extend the use of such cranked axles made of chrome-nickel steel.

The Paris-Lyons-Mediterranean Railway uses axles made of chrome-nickel steel hardened and tempered, and axles made of nickel steel.

1° Axles of chrome-nickel steel.

The chrome-nickel steels have an ultimate tensile strength of 64 to 87 kilograms (91,000 to 123,700 lb. per square inch), an elongation of 15 to 23 per cent measured on a length of $l/\sqrt{80S}$, and an elastic limit of 38·6 to 64 kilograms per square millimetre (54,900 to 91,000 lb. per square inch). A drop test is made followed by a bending test in the press till the test piece breaks or is doubled up.

All the test pieces are cut lengthways.

The chromium content varies between 0·12 and 0·5 per cent, and the nickel content between 1·07 and 2·6 per cent.

The trials have as yet not gone very far; however several premature failures have been recorded, such as :

1° 150,000 kilometres as against 332,000 kilometres (93,200 miles as against 206,300 miles) ordinary steel, 33 per cent of that series of locomotives being equipped with special-steel-axles. But there are still two axles running out of four put in in 1897; 2° 48,000 kilometres as against 119,000 kilometres (29,800 miles as against 73,900 miles) for axles of ordinary steel. But there is still one axle running out of two put in in 1897 on that series of locomotives, 3 per cent of which were equipped with such special-steel axles; 3° 176,000 kilometres as against 322,000 kilometres (109,400 miles as against 200,000 miles), 33 per cent of these locomotives being equipped with such special-steel axles. But there are still four axles running out of five put in in 1899. One also finds more satisfactory mileages of 246,000 kilometres (152,900 miles) with special steel as against 232,000 kilometres (144,200 miles) with ordinary steel, 24 per cent of these locomotives being equipped with special steel, and fifteen axles still running out of eighteen put in in 1900.

2° Axles of nickel steel.

3 per cent of those in use have given ultimate tensile strengths of less than 60 kilograms per square millimetre (85,300 lb. per square inch), and consequently do not come within the scope of our report. 6 per cent have given ultimate tensile strengths of 55 to 63·6 kilograms per square millimetre (78,200 to 90,500 lb. per square inch), with elongations of 17·6 to 24·5 per cent measured on a length of $l/\sqrt{80S}$, and elastic limits of 42 to 52 kilograms per square millmetre (59,700 to

74,000 lb. per square inch). A drop test is made followed by a bending test in the press till the test piece breaks or is doubled up.

All the test pieces are cut lengthways. These axles were ordered to contain 6 per cent of nickel.

The mileage was 225,000 kilometres as against 275,000 kilometres (139,800 miles as against 170,900 miles) with axles of ordinary steel; 28 per cent of the locomotives were so equipped. There are still three axles in use out of five put in 1900 on one series of locomotives, and five out of five in the case of another series.

Switzerland.

The St. Gothard Railway uses for the cranked axles of its compound locomotives nickel steel having an ultimate tensile strength of 59 to 61 kilograms per square millimetre (83,900 to 86,800 lb. per square inch), with an elongation of 20 to 21 per cent measured on a length of $100\frac{l_1 - l_0}{l_0}$, and a contraction of area of 46 to 49 per cent.

The nickel content varies between 5 and 7 per cent. This company gives no working results.

The Federal Railway uses nickel steel for the cranked axles of the compound locomotives with two, three and four cylinders, and for those of the three-cylinder locomotives using superheated steam. This steel has an ultimate tensile strength of 60 to 67·5 kilograms per square millimetre (85,300 to 96,000 lb. per square inch), with an elongation of 18 to 21 per cent measured on a length of 200 millimetres (7 7/8 inches) or of $11{\cdot}3\sqrt{F}$, and a contraction of area of 45 to 52 per cent. This railway will not extend the use of nickel-steel axles as no failures occur with the ordinary axles, and it has as yet observed no difference in the wear of rubbing surfaces of the two kinds of steel used.

GENERAL CONCLUSIONS.

We think that the following conclusions can be drawn from the particulars reported :

1° Actual use.

A fairly considerable number of railways is making trials of cranked axles for locomotives, made of special steel of high resistance. The experimental period is not yet concluded, and there is only one company, the French Northern Railway, which appears to have definitely decided to extend this application.

2° Mechanical tests.

All the special steels tested up till now only give good results with test pieces cut lengthways. As usually the cracks occur in those parts of the cranked axles which are subjected to stresses crossways, the tests explain the premature failures observed in practice.

3° Metallurgy.

The special metals always require heat treatment, such as quenching and tempering, which the steel works producing them work out for their own products.

The nickel steels seem, up till now, to give less good results than the chrome-nickel steels, particularly if their nickel content reaches or exceeds 6 per cent. It is, however, to be noted that the carbon content modifies to a very important extent the properties of metal containing the same nickel content; hence one must not be too absolute as far as the maximum nickel content is concerned.

4° Future development of the use of such steels.

The earlier results as regards the mileage of axles of ordinary steel, obtained with the French Eastern 4-6-0 locomotives having 2 metre (6 ft. 6 $^{3}/_{4}$ in.) driving wheels, lead us to think that other things being equal, it is the factor " speed " which has the greatest influence on the life of a cranked axle. As the speeds are not likely to decrease, and as ordinary steel does not give a sufficient mileage in the case of certain series of locomotives, we think that this use will become extended, at least in the case of high speeds. The results of the trials now being made will make it possible to determine more accurately the best chemical composition to use.

III. — Tires.

Denmark, Bulgaria.

The Danish State and the Bulgarian State railways use tires similar to the tires of class B of the standard specification of the French railways, which will be referred to further on. The only difference is that these systems sometimes specify crucible steel, whereas the French railways allow the open-hearth process to be used.

We have received no information as to the results obtained with these tires in practice.

Italy.

The Italian State Railway uses for its locomotives and tenders crucible-steel tires having an ultimate tensile strength of 75 to 85 kilograms per square millimetre (106,700 to 120,900 lb. per square inch) with an elongation of 12 to 15 per cent measured on a length of 50 millimetres (1 $^{31}/_{32}$ inch). The drop test consists of

three 5,000 kilogrammetres (36,165 foot-pounds) blows; no fracture or crack must appear.

We have received no information as to the results obtained with these tires in practice.

France.

All the French railways use tires, in ordinary practice, having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,600 lb. per square inch) and an elongation of 14 per cent measured on a length of $l/\sqrt{66{\cdot}678}$. These tires are accepted subject to the following tests : class B, three blows of 10,000 kilogrammetres (72,330 foot-pounds ; class C, six blows of 10,000 kilogrammetres (72,330 foot-pounds); class D, bent in the press, and then restored by blows; no fractures or cracks must appear, according to the systems ordering them. One tire is tested out of each heat. We only refer to these tires by way of comparison with what follows, as we do not consider them to come within the scope of this report.

The Orleans Railway in 1892 fitted twenty tires to shunting locomotives, made of steel having an ultimate tensile strength of 88·8 kilograms per square millimetre (126,300 lb. per square inch) and an elongation of 9·2 per cent. In consequence of fractures while in use, the remaining fifteen tires were taken out. They had run about 40,000 kilometres (25,000 miles) and had become worn as much, if not more, than tires of ordinary steel.

The French Eastern Railway has recently started trials with three extra-hard steels : 1° containing carbon ; 2° chromium ; 3° nickel.

Their chemical compositions are as follows :

—	Carbon.	Silicon.	Manganese.	Chromium.	Nickel.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	From 0·65 to 0·59	From 0·25 to 0·39	From 0·73 to 0·52	...	...
Chromium . . .	0·58	From 0·27 to 0·31	From 0·61 to 0·59	From 0·53 to 0·47	...
Nickel	0·6	...	...	...	> 3

The carbon-steel tires are hardened and tempered ; the chrome-steel tires are not subjected to any heat treatment, but the rolling is finished at a low temperature ; the nickel-steel tires also have their rolling finished at a low temperature and are then tempered, the maximum temperature being under 700° C. (1,252° Fahr). These tires are accepted, subject to the conditions of class C of the standard specification (six blows of 10,000 kilogrammetres [72,330 foot-pounds]) ; but the ultimate tensile strength must be at least 85 kilograms per square millimetre (120,900 lb. per square inch) with an elongation of 7 per cent measured on a length of $l/\sqrt{66{\cdot}678}$.

The C-tire steel has the following average percentage composition : carbon, 0·51; manganese, 0·73; and sometimes 0·25 of sillicon.

The extra-hard tires are mounted on pony-truck wheels, coupled wheels, bogie wheels, and wheels of heavily-loaded tenders. The last three classes of wheels are braked.

The results obtained in practice are as follows, the distances given corresponding to a wear at the rolling surface of 3·5 millimetres ($^{9}/_{64}$ inch).

—	Pony trucks.	Coupled wheels.	Bogies.	Tenders.
	Kilometres (miles).	Kilometres (miles).	Kilometres (miles).	Kilometres (miles).
Carbon	34,000 (21,130) (1)	47,000 (29,200)	77,000 (48,850)	84,000 (52,200)
Chromium	65,000 (40,400)	53,000 (32,930)	97,000 (60,270)	60,000 (37,300) (1)
Nickel	...	65,000 (40,400)	97,000 (60,270)	84,000 (52,200)
Ordinary steel C . .	37,000 (23,000)	35,000 (21,750)	51,000 (31,700)	83,000 (51,570)

But it is to be noted that a great mileage for a given amount of wear is not the only quality the tire requires to possess, in addition to that of toughness, which is of paramount importance.

It, in fact, frequently happens that small pieces, like straws, become torn out more or less completely from the rolling surface, and make it necessary to re-turn the surface sooner, or to take out a tire having a mean thickness still considerably exceeding the regulation thickness. Defects of this sort (called " reediness ") are very objectionable as they involve not only a considerable reduction in the thickness of the tire when it is re-turned, but also a corresponding reduction in the second tire of the same axle which otherwise would often have only required very little truing at its rolling surface. We have no definite opinion as to the origin of these defects, which the railway administrations naturally would attribute to flaws in the steel, and the steel-makers to shocks from the brakes and blows given by the ends of rails or the track appliances.

Be the reason what it may, if we classify the four qualities of steel used on the French Eastern, the order of merit is :

1° Nickel steel;
2° Chrome steel;
3° Carbon steel;
4° Ordinary steel C of the standard specification.

It is to be noted that the two last steels give practically equivalent results.

In these experiments with tires, the wear varied not only with different series of

(1) These results must be received with caution, because they apply to a very small number, and one single case can falsify the mean considerably.

locomotives and tenders, but also, at least on the French Eastern system, with the stations at which the locomotives were used. This comes to the same thing as saying that the wear varies with the profile of the track, for a shunting locomotive only moves, as a rule, on a well-determined section of line. These variations are very important, and the mileage may vary from single to double, for the same amount of wear : much attention must, therefore, be paid to this point when drawing up statistics.

Switzerland.

Rhetian Railway. — This railway uses tires having an ultimate tensile strength of 70·4 to 93·4 kilograms per square millimetre (100,100 to 132,800 lb. per square inch), with an elongation of 11·8 to 16·9 per cent and a contraction of are of 24 to 60 per cent; these tires are used for the carriages and wagons, with two or four braked axles and with a maximum axle-load of 10 tons (9·84 English tons). The drop test is carried out on at least 1 per cent of the tires, with a maximum of one test per heat. The 3,000 kilogrammetre (21,700 foot-pounds) blows must reduce the inner diameter at least 12 per cent before fracture or cracks appear. The locomotive tires are made of the same steel, but are fixed by a lip, the tires of the carriages and wagons being secured by set screws.

We have received no information as to the results obtained with these tires in practice.

St. Gothard Railway. — This railway uses tires made of Martin steel having on the average an ultimate tensile strength of 75 kilograms per square millimetre (106,700 lb. per square inch), with an elongation of 16 to 18 per cent measured on a length of $100\,\frac{l_1 - l_0}{l_0}$ and a contraction of area of 30 to 40 per cent. They are subjected to drop tests in which blows varying from 3,000 to 5,000 kilogrammetres (21,700 to 36,165 foot-pounds) are used. Up to fifteen blows are given by the tup before fracture occurs. These tires are reheated and cooled slowly after they have been rolled.

They are fitted on wheels with axle-loads of 15 to 16 tons (14·8 to 15·7 English tons) in the case of drivers and of 10 to 14·5 tons (9·84 to 14·3 English tons) in that of carrying axles. They are braked 60 to 70 per cent of the adhesive weight. They are fixed to the wheels by Mansell rings and screws. The setting is effected with care.

The results obtained in practice as compared with those given by tires of ordinary steel are as follows :

—	Wear per 1,000 kilometres (per 1,000 miles) run.
Special tires	0·104 to 0·119 millimetre (0·0066 to 0·0075 inch).
Ordinary tires	0·152 to 0·176 — (0·0096 to 0·0112 —

The mean mileage run before the first re-turning by these special tires, is 50,000 kilometres (31,000 miles) in the case of express locomotives and 70,000 to 80,000 kilometres (43,500 to 49,700 miles) in that of other locomotives.

Federal Railway. — Crucible-steel tires are used, having an ultimate tensile stregth of 80 kilograms per square millimetre (113,800 lb. per square inch) and an elongation of 10 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches). 1 per cent of those supplied are subjected to the drop test; they must stand a reduction of 12 per cent of the diameter without fracture or cracks appearing. A blow of 3,000 kilogrammetres (21,700 foot-pounds) is applied and increased by 500 kilogrammetres (3,616 foot-pounds) each blow as long as the deformation produced by the preceding blow is less than 10 milimetres ($^{25}/_{64}$ inch). The test is continued until the diameter has been reduced by at least 12 per cent.

We have received no information as to the results obtained with these tires in practice.

GENERAL CONCLUSIONS.

We think that the following conclusions can be drawn from the particulars reported :

1° Actual use.

A fairly considerable number of railways use in ordinary practice steel having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,600 lb. per square inch). But there are few trials of steels having a greater ultimate tensile strength specified than 80 kilograms per square millimetre (113,800 lb. per square inch) as a minimum.

2° Mechanical tests.

All the companies take care, and that quite justly, to ensure the toughness of the tires, by using drop tests. The harder the tire, the stricter, in our opinion, must one be in observing the drop-test specification.

3° Metallurgy.

According to the observations of the French Eastern Railway, we see that metallurgists have tried to obtain the hardness required, without brittleness : 1° by heat treatments; 2° by the addition of chromium or of nickel. We think that the results show the second method to be at present superior.

4° Future development of the use of such steels.

The hardness of the present rails is similar to that of ordinary tires, the speeds and the loads are increasing, or at least are not likely to become reduced. We

think that, at least in the case of certain axles specially loaded or braked, one will necessarily be led to use tires harder than the 70 kilograms (99,600 lb. per square inch) tires now ordinarily used on several railways.

IV. — Miscellaneous parts.

Denmark.

The Danish State Railway uses steel, similar to that used for its tires, for the return cranks; and nickel steel, similar to that used for its cranked axles, for the crank-pins and gudgeon-pins.

We have received no information as to the results obtained with these steels in practice.

Italy.

The Italian State uses for piston rods, cross-heads and slide bars, crucible steel having a minimum tensile strength of 65 kilograms per square millimetres (92,500 lb. per square inch), with a minimum elongation of 12 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches).

We have received no information as to the results obtained with these steels in practice.

France.

Several French railways use locomotive spring saddles made of manganese-steel castings. This steel is very hard and can only be worked by grinding. It has the advantage over case-hardened (cemented and quenched) steels, that it is of uniform hardness throughout its thickness, and consequently, the wear is more uniform when it is used.

The French Northern Railway is making a trial of straight locomotive axles, 1·5 per cent of the locomotives being so equipped. These axles are made of chrome-nickel steel, similar to that used for the cranked axles. This company has also a certain number of cranks and crank-pins in use, also made of the same kind of steel.

The trials are not sufficiently advanced to give any working results.

Switzerland.

The Federal Railway uses spring hangers made of nickel steel having an ultimate tensile strength of 60 kilograms per square millimetre (85,300 lb. per square inch), an elongation of 18 per cent and a contraction of area of 45 per cent.

We have received no information as to the results obtained in practice.

APPENDIX.

Detailed list of questions relating to subject V-B.

I. — Tires of special steel of high resistance.

Use.

1. Do you use these tires in ordinary practice?
2. Do you use them as an experiment?
3. Do you intend to make a trial?
4. On axles :

   On driving axles :
5. Heavily loaded (locomotives and tenders)? Give average axle-load.
6. Braked (locomotives and tenders)? What percentage of the weight of the vehicle?

   Carrying :
7. For carriages and wagons?

Conditions of manufacture.

8. Specified : open-hearth, crucible, converter.
9. Large ingots cut up or an ingot per tire.
10. Amount of head specified.
11. Discretion as to manufacture: which of the above conditions are selected by the steel makers?
12. What heat treatment is the tire subjected to after it has been rolled?

Specification.

13. Ultimate tensile strength in kilograms per square millimetre of original section : specified, obtained.
    Elongation per cent of length between datum marks : specified, obtained.
    What formula is used in calculating the elongation per cent?
    Elastic limit : specified, obtained.
    Contraction of area : specified, obtained.
    Are the conditions specified minima or average?
14. Drop test :
    Weight of tup.
    Height of drop : do you proportion the height of the drop to the thickness or diameter of the tire tested?

What is the proportion?
Number of blows of tup before fracture : specified, obtained.
What measurements are taken after each blow of the tup?

15. Tests in the press, or other tests.

16. Chemical composition : specified, actual.

Working results.

17. Mean wear as compared with ordinary-steel tires mounted on the same vehicles.

18. Mean mileage before the re-turning.

19. To how many tires does this information apply?

20. What is the percentage of special tires as compared with the ordinary-steel tires in use?

21. How are the tires fixed to the rim : bolts, set-screws, or lips?

22. Are special precautions taken when putting on the tires as to dents, damage to the grain given to the steel in the rolling mill, or cracks when lips are used as a fastening?

23. Fractures or incidents while in use or at the workshops.

24. Are you inclined to extend the use of these tires and to what extent?

II. — Axles of special steel of high resistance.

I. — Cranked axles.

Use.

1. Do you use these axles in ordinary practice?

2. Do you use them as an experiment?

3. Do you intend to make a trial :

4. On locomotives with two, three of four cylinders, compounds or non-compounds?

5. Position of the cranked axle relatively to the other axles. Is it coupled?

Conditions of manufacture.

6. Specified open-hearth, crucible, converter.

7. Amount of head specified for the ingots.

8. Discretion as to manufacture : which of the above conditions are selected by the steel makers?

9. What heat treatment is the axle steel subjected to after it is forged and rough machined, if the latter is done?

Specification.

10. Ultimate tensile strength, in kilograms per square millimetre of original : specified, obtained.
Elongation per cent of length between datum marks : specified, obtained.

What formula is used in calculating the elongation per cent?
Elastic limit : specified, obtained.
Contraction of area : specified, obtained.
Are the conditions specified minima or average?

11. Drop test :
Dimensions of the test pieces.
How taken : at the end, in the webs, lengthways or crossways.
Weight of tup and height of drop.
Number of blows.
Distance between supports.
Faces of the test piece which receive the successive blows.
Results specified.
Results obtained.

12. Other tests.

13. Chemical composition : specified, obtained.

Working results.

14. Reason for withdrawal.

15. Average number of kilometres, according to type of locomotive, before withdrawal.

16. Comparison with ordinary-steel axles for the same series of locomotives.

17. Percentage of the special-steel axles relatively to the ordinary-steel axles.

18. Fractures or incidents while in use.

19. Are you inclined to extend the use of these axles and to what extent?

II. — Straight axles.

Use.

1. Do you use these axles in ordinary practice?

2. Do you use them as an experiment?

3. Do you intend to make a trial :

4. On locomotives with two, three or four cylinders, compounds or non-compounds?

5. Are these axles driving, coupled, or merely carrying axles?

Conditions of manufacture.

6. Specified : open-hearth, crucible, converter.

7. Amount of head specified for the ingots.

8. Discretion as to manufacture ; which of the above conditions are selected by the steel makers?

9. What heat treatment is the axle steel subjected to after it is forged and rough machined, if the latter is done?

Specification.

10. Ultimate tensile strentgh, in kilograms per square millimetre of original section : specified, obtained.
Elongation per cent of length between datum marks : specified, obtained.
What formula is used in calculating the elongation per cent?
Elastic limit : specified, obtained.
Contraction of area : specified, obtained.
Are the conditions specified minima or average?

11. Drop test :

On test pieces :

Dimensions of the test pieces.
Weight of tup and height of drop.
Number of blows.
Distance between supports.
Faces of the test piece which receive the successive blows.
Results specified.
Results obtained.

On axles :

Do you test the ends, the body?
What rules are observed : for the weight of the tup; the height of the drop; the number of the blows?
For the ends and the body according to their dimensions. Distance between the points of support or grips.
Do you bend and straighten the ends or the body by blows?
What measurements are taken during this bending and straightening?
Results specified.
Results obtained.

12. Other tests.

13. Chemical composition : specified, obtained.

Working results

14. Reason for withdrawal.

15. Average number of kilometres, according to type of locomotive, before withdrawal.

16. Comparison with ordinary-steel axles for the same series of locomotives.

17. Percentage of the special-steel axles relatively to the ordinary-steel axles.

18. Fractures or incidents while in use.

19. Are you inclined to extend the use of these axles and to what extent?

III. — Springs of special steel of high resistance.

Use.

1. Do you use these steels for springs in ordinary practice?
2. Do you use them as an experiment?
3. Do you intend to make a trial :
4. For what class of vehicle :
   Locomotive, driving axles or carrying axles.
   Tenders.
   Passenger carriages and luggage vans.
   Goods wagons.
5. What are the forms of these special springs : with parallel plates, helical, volute, etc.

Conditions of manufacture.

6. Specified : open-hearth, crucible, converter.
7. Discretion as to manufacture : which of the above conditions are selected by the steel makers?
8. What conditions of hardening and tempering are used in the case of spring steel before its final conversion into springs?

Specified tests.

9. How do you measure the elastic deflection of the bar selected for testing? Length of the bar, initial camber test load, reduction in camber showing elastic limit is reached, etc.
10. Results specified.
    Results obtained.
11. Tensile tests of the steel.
    In what state, from the point of view of the heat treatment it has been subjected to, is the bar from which the test piece is cut? Is the test piece subjected to any heat treatment after it has been cut out?
    What particulars do you observe when making the tensile tests?
    Results specified.
    Results obtained.
12. Drop tests :
    What has been the heat treatment of the test pieces used for the drop test (quenched, annealed, etc.)?
    Dimensions of the test pieces.
    Number and force of the blows, weight of tup, distance between supports, etc.
    Results specified.
    Results obtained.
13. Sundry tests : shearing, quenching at a red heat, etc.

14. Chemical compostion : specified, actual.

15. Working results.
At what amount of elastic deflection does the spring work when under normal load?
Comparison with ordinary steel from this point of view.
Loss of camber and fractures of the springs while at work.
Appearance of fractures during use. Comparison with ordinary steel.

16. Are you inclined to extend the use of these special steels and to what extent?

Plate of special steel of high resistance.

Use.

1. Do you use special steel for plates, in ordinary practice?

2. Do you use it as an experiment?

3. Do you intend to make a trial?

4. For what purpose : boilers, frame plates?

Conditions of manufacture.

5. Open-hearth, crucible.

6. Cropping the ingots or plates. What are the proportions removed from the bottom of the ingot?
Specified.
Carried out by the steel makers.

7. What heat treatment is the plate subjected to before it is submitted for acceptance.

Specification.

8. Tensile tests :
Particulars of the elastic limit, ultimate tensile strength, elongation per cent (formula used), contraction of area, etc.
Specified.
Obtained.

9. Drop tests, hot and cold heating, and miscellaneous.

10. Chemical composition : specified, obtained.

Working results.

Difficulties of flanging.
Advantage of weight as compared with ordinary steel.
Corrosion in the case of boilers.
Fracture by cracks or flaws.

11. What proportions of such plates are in use as compared with plates of ordinary steel?

12. Are you inclined to extend the use of these plates?

*

V. — Couplings of special steel of high resistance.

1. Do you in ordinary practice use special steel for parts of the couplings?
2. Do you use it as an experiment?
3. Do you intend to make a trial?
4. Which parts of the couplings do you make of such special steel : screws, nuts, links, hooks?

Conditions of manufacture.

5. Specified : open-hearth, crucible.
   Selected by steel makers.
6. What heat treatment is the bar subjected to before it is submitted for acceptance?

Specification.

7. Tensile tests : particulars of the elastic limit, ultimate tensile strength, elongation per cent (formula used), contraction of area.
8. Bending tests, drop tests, etc.
9. What heat treatment have the test pieces had before the test?
10. Chemical composition of the steel : specified, obtained.

Working results.

11. What heat treatment are these parts subjected to after forging or stamping?
12. Advantage as regards weight.
13. Advantage as regards strength : tests of specimens of special steel compared with tests of specimens of ordinary steel of the same type.
14. What proportion of such parts of special steel are in use, as compared with similar parts of ordinary steel or iron?
15. Are you inclined to extend the use of these steels and to what extent?

VI. — Miscellaneous parts of special steel of high resistance.

Use.

1. Do you in ordinary practice use special steel for miscellaneous parts?
2. Parts of what kind?
3. What are the particulars of the physical and chemical tests of these steels?
4. Are you inclined to extend their use and to what extent?

[621 .131.2 & 625 .246]

REPORT N° 2

(America)

By D. F. CRAWFORD,

GENERAL SUPERINTENDENT OF MOTIVE POWER, PENNSYLVANIA LINES WEST OF PITTSBURGH.

INTRODUCTION.

The general use in America of steel in locomotive construction for many years, and the almost general adoption of steel or partial steel construction for freight cars during the past ten or fifteen years, as well as the rapidly increasing use being made of steel in the construction of passenger equipment cars, precludes your reporter from giving a fully detailed statement of its many uses. I will, therefore, only endeavour to give the results obtained by the use of the steel or partial steel structures from a general operating and maintenance standpoint, rather than to attempt to discuss such a far reaching subject from a purely technical or designers point of view, and will submit some drawings to indicate typical designs.

Locomotives.

General. — In locomotive construction in America steel has been used for many years for the following parts :

Boilers, fire-boxes, axles, connecting rods, piston rods, springs, tires, general

sheet work, such as the tender tank or cistern, smoke box, running boards, etc., and recently steel tubes. Steel castings have been used for driving wheel centers, frames and driving boxes, and has been substituted for many parts formerly of cast iron or forgings.

Boilers. — The following specifications will indicate the quality of steel generally used for boiler shells :

Tensile strength	55,000 to 65,000 lb. per square inch.
Elongation (in 8 inches)	26 to 20 per cent.
Carbon	0·18 per cent.
Phosphorus : not above	0·04 —
Manganese : not above	0·40 —
Silicon not : above	0·05 —
Sulphur : not above	0·03 —
Copper : not above	0·03 —

Fire-boxes. — Steel for this purpose is required to be of about the quality given below :

Tensile strength	55,000 to 65,000 lb. per square inch.
Elongation (in 8 inches)	28 to 22 per cent.
Carbon	0·18 per cent.
Phosphorus : not above	0·03 —
Manganese : not above	0·04 —
Silicon : not above	0.02 —
Sulphur : not above	0·02 —
Copper : not above	0·03 —

While there is some variation in the above requirements made in the specifications promulgated by the different railroads and locomotive builders, these variations are so slight that the above specifications may be said to cover quite well the quality of steel in general use.

Experiments with boiler steels of special composition have been made and are in progress, but no data has yet been obtained which is sufficiently definite, in the opinion of your reporter, to warrant its submission to the Congress.

The experience of the American railroad mechanical men of the present day is confined to steel boiler and steel fire-box, and therefore no comparison with fire-boxes of other materials is available.

The steel fire-boxes last from three to twelve years; depending somewhat on the nature of the service in which the locomotive is used and the quality of the water available in the district, as well as the design of the boiler and fire-box. In general, the life obtained from the wide fire-boxes used on many locomotives at the present time, is not as long as that obtained from the narrow fire-boxes previously in general

use. The average life of fire-boxes obtained in two groups of locomotives coming under the writer's observation is as follows :

A. — Fire-box	40 inches	wide,	average life	85 months.
B. — —	66 —	—	. . . . .	57 —

The causes assigned for this difference have been as follows :

1° With the wider fire-boxes, the fire is thin immediatly adjacent to the side sheets, causing rapid variation in the temperature at the side sheets;

2° The straight sides of the wider fire-boxes do not present the same opportunity for expansion and contraction as the curved sheets used in the narrow construction;

3° The circulation of water is more favourable with the curved sheets.

This matter is now receiving the attention of the mechanical departments of several railroads and useful information will at least be obtained, even if sufficient data to justify a change in design is not obtained.

The information given above regarding the effect of the design of the fire-boxes on the life of same is included in this report, on account of the fact that there has been some tendency to consider special steels for fire-boxes with a view of prolonging their life.

Tubes. — For many years it has been the general practice on American railroads to use for boilers, tubes made of charcoal iron. For the past ten years, however, the number of tubes made of steel has increased and at the present time steel tubes are used exclusively on some roads. Both the seamless drawn tube and the lap welded tubes of steel are used.

The quality of the steel used for tubes is indicated by the following :

Tensile strength	50,000 to 60,000 lb. per square inch.
Elastic limit.	30,000 to 35,000 — — —
Elongation (in 8 inches)	25 to 20 per cent.
Carbon	0·10 to 0·16 per cent.
Phosphorus	0·008 to 0·010 —
Manganese	0·39 to 0·49 —
Sulphur	0·03 to 0·025 —

Steel tubes have not been in use a sufficient length of time to determine whether they will eventually entirely supplant the wrought iron tube, but the large increase in their use by many roads would indicate favourable results.

The lower cost of the steel tube as compared with the wrought iron tube led to their trial and the results obtained seemed to warrant their further consideration.

The success obtained with the steel tube will undoubtedly depend somewhat on the quality of the water used, as, up to the present time, it would appear that with water containing corrosive materials the steel tube is affected by corrosion more rapidly than the iron tubes.

An interesting use of the seamless steel tube is for safe ending (that is, welding on a short piece of tube to make up for loss occuring in cutting the tube to remove it from the boiler) wrought iron tubes with steel. On one road operating about eighteen hundred locomotives, it has been the practice to use seamless steel tubing for safe ends for several years, for the following reasons:

1° Steel ends stand up better under the repeated caulking and beading required, thus the time between resetting of tubes is prolonged;

2° Reduction in cost of material as compared with charcoal iron and reduced maintenance cost on account of prolonged life of the tubes;

3° The life of the wrought iron tubes already in service was prolonged, as safe ending is less frequent;

4° Less length of the steel tube subject to corrosion as compared with the entire steel tube.

Axles. — Carbon steel of about the following composition has been used in the manufacture of locomotive axles for many years:

Carbon	0·40 per cent.
Manganese	0·50 —
Silicon	0·20 —
Phosphorus : not above	0·03 —
Sulphur : not above	0·03 —
Copper : not above	0·03 —

Some experiments have been made with axles of steel containing nickel, but as yet the results obtained do not seem to justify the use of this material.

Steel containing vanadium has also been used for a few axles now in use for trial.

From both a strength and service standpoint, the carbon steel axle may be considered satisfactory, but with the larger sizes precaution is necessary to obtain solid billets, and in some cases it is the practice to bore a hole about two inches in diameter from end to end in the center of the axles of the larger sizes to permit of interior inspection.

Connecting rods and piston rods. — These parts are made of a steel somewhat similar to that used for axles; that is :

Carbon	0·45 per cent.
Manganese	0·50 —
Silicon	0·05 —
Phosphorus	0·03 —
Sulphur	0·02 —
Copper	0·03 —

Formerly, with lighter locomotives, both the connecting rods and piston rods were made of wrought iron.

Springs. — The steel used for springs is of about the following composition :

	Elliptical springs.		Helical springs.	
Carbon	1·00 per cent.		1·00 per cent.	
Phosphorus : not over . .	0·03	—	Not over : 0·05	—
Manganese : not over . .	0·25	—	— 0·25	—
Silicon	0·20	—	— 0·10	—
Sulphur : not over . . .	0·03	—	— 0·03	—
Copper : not over. . . .	0·03	—	...	

With the heavier loads now carried by the springs, some difficulty has been experienced in obtaining satisfactory service, and the chemistry of spring steel, as well as the heat treatment and method of manufacture, is receiving the attention of the railroad mechanical engineers and the spring manufacturers.

Springs made of steel containing vanadium are being used experimentally, and laboratory tests of the material are at least promising ; although the service tests have not been of sufficient duration to permit conclusions being drawn.

Tires. — The steel tires have, of course, been used for many years and little change in the manufacture, other than insuring a more uniform product, has been made.

The rapid wear of the tires used on locomotives having wheel weights of from 25,000 to 31,000 pounds, and, as the tires must be removed from the wheels of such locomotives when one and one-half times as thick as was the case with locomotives having less weight per wheel, on account of rolling out and becoming loose, coupled with the fact that tire truing and renewals are a constant source of expense, indicates the importance of further study of this subject.

Tires of specially heat-treated steels or steels containing nickel, vanadium or other alloys have only had, to the present time, limited trials.

Steel castings. — With the advent of heavier locomotives, the desirability of obtaining material of greater strength than cast iron led to the adoption and almost general use of steel castings in place of cast iron for the following locomotive parts :

Driving wheel centers, driving boxes and truck boxes, eccentrics, eccentric straps, frame braces, pistons (centers), as well as many of the other castings used.

The development of the manufacture of steel castings for the above mentioned purposes permitted their manufacture at a cost which made their use attractive as a substitute for many of the parts which had been made of wrought iron, and many locomotives have been built having the parts named below made of steel castings instead of wrought iron :

Frames, spring rigging, stirrups, saddles, hangers and equalizers, valve motion parts, guides and guide yokes, cross heads and many of the smaller forgings.

Steel castings for the purposes mentioned above have about the following chemical and physical qualities :

Tensile strength	60,000 to 80,000 lb.
Elongation	25 per cent.
Carbon	0·27 per cent.
Phosphorus	0·05 —
Manganese	0·57 —
Silicon	0·25 —
Sulphur	0·03 —

It is required that all steel castings be carefully annealed.

Frames. — Probably the most interesting use of steel castings in locomotive construction is in the manufacture of the locomotive frames of the bar type used almost exclusively in America.

Figure 1 shows the construction of the forged frames, with the back bone and pedestal legs forged in one piece, welding only being permitted in the pedestals legs at the point of junction with the back bone. Separate forgings were used for the pedestal braces or lower members, bolted on as shown.

Figure 2 shows the form of construction generally used since about 1885. In this form the lower member or pedestal brace is forged with the remainder of the frame, avoiding the use of the separate pieces and bolts, welds being permitted at the junction of the pedestal brace and pedestal legs as well as at the back bone.

Figure 3 shows a frame a number of which have been made of wrought iron forged in the same manner as that covered by figure 2, and a number have been made of steel castings.

The frame shown in figure 3 requires a single steel casting weighing about 3,500 lb. and the various manufacturers have succeeded in producing this rather difficult casting in such a manner that the results obtained in service compare favorably with the results obtained with the more expensive wrought iron forgings.

Steel casting frames are being used in the majority of locomotives constructed at the present time.

As is the case with other parts of the locomotive, steel containing vanadium, nickel, etc., is used experimentally.

Steel castings for the various parts formely made of either cast or wrought iron are used both in the construction of new locomotives or substituted in repairs when the parts fail in service or the necessity for the stronger and less expensive material is apparant.

Tenders, Cabs, etc. — Steel has also been substituted for wood in locomotive construction, and in the latest machines built, wood has almost been eliminated. Formerly the tender frame, cab, pilot or bumper beam and running boards were built of wood. At present the tender frame is built up of structural steel and steel

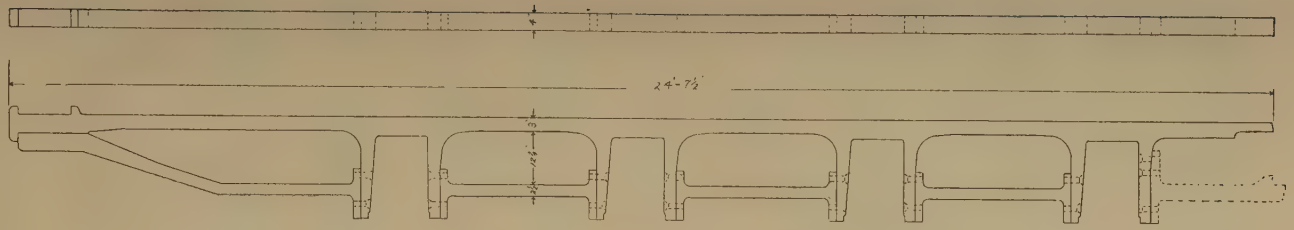


Fig. 1.

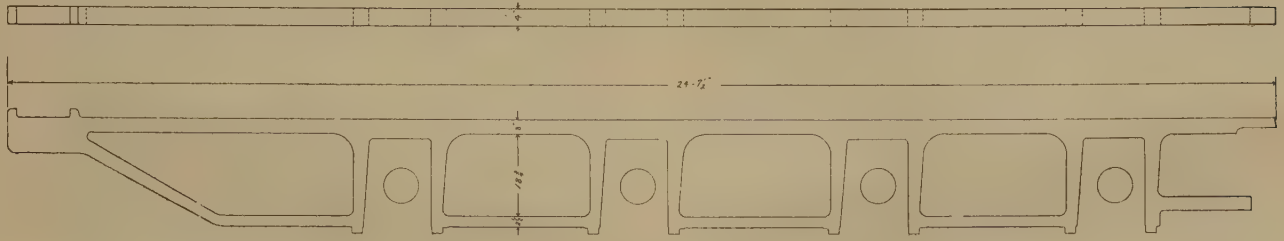


Fig. 2.

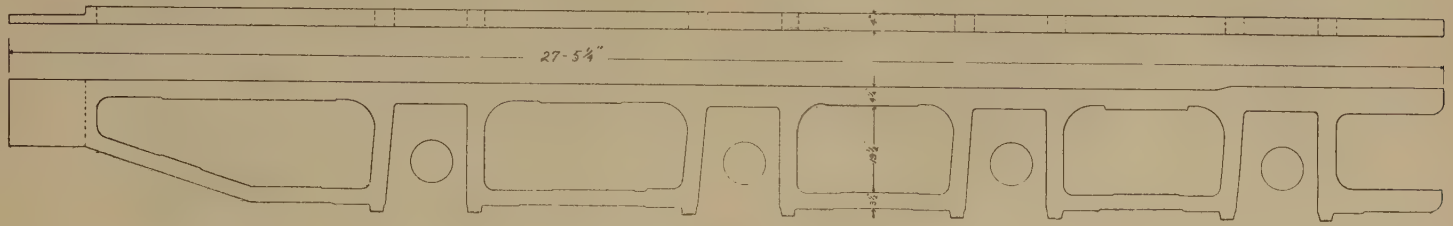


Fig. 3.

castings, the cab of steel sheets and shapes (although generally lined with wood to avoid condensation on the metal and to reduce the conductivity), the running boards of sheet steel and the pilot or bumper beams of steel castings.

CONCLUSIONS.

In locomotive construction steel has been substituted for other materials for the following reasons :

1° Greater strength, permitting use of relatively smaller and lighter parts;

2° Stronger material necessary to meet the demand made by the more powerful and consequently heavier locomotives constructed at the present time;

3° Lower first cost and reduced maintenance cost as compared with the other materials if used on the present heavy locomotives.

For the reasons given above, the use of steel, without doubt, will be extended to include practically all parts of the locomotives, other than certain of the wearing surfaces which will be of bronze or of other bearing metal or of cast iron.

Freight cars.

General. — Steel is used so extensively in freight car construction at the present time in America that your Reporter will only attempt to give some examples of its use and submit drawings and photographs of cars constructed of it.

The construction of freight cars built prior to about 1897 is illustrated by figure 37, which shows the complete wooden underframe. In this construction only the axles, springs and couplers are of steel, except in some cases the well known Fox pressed steel truck was used.

About 1895 pressed steel stake pockets and pressed steel body bolsters were introduced in car construction, and in a short time, the pressed steel truck bolster followed. Steel casting truck bolsters were also used about this time.

Figure 4 shows the pressed steel body bolster and figure 5 the pressed steel truck bolster. The steel casting truck bolsters were similar in form to the pressed steel bolster.

Figure 31 illustrates the usual wooden construction with steel body bolster substituted for the wooden or composite bolster formerly used.

The advent of the steel bolster was welcomed by the railroads, as with the ordinary wooden, trussed wooden or composite bolster much difficulty was experienced on account of the bolster sagging at the ends, which not only caused

high maintenance costs but permitted the top and bottom side bearings to come in contact, thus increasing the resistance, especially on curves, which diminished the train load.

In 1895, the car illustrated by figure 26 was built and was one of the earliest of the so-called self-cleaning hopper type constructed.

In 1897, the Schoen Pressed Steel Car Company built the first cars of the type illustrated by figure 27 which, it will be seen, follows the lines of wooden car illustrated by figure 26.

Since 1897 to the present time, there has been rapid development and increase in the use of the steel for both the parts of freight cars and for the entire construction, development of both the design and construction building up a great industry.

Number of steel and steel underframe cars. — In twelve years, there have been built by the larger car manufacturing companies approximately 311,000 all steel and 242,000 steel underframe cars, divided in kinds as follows :

All steel.

Box	18
Gondolas, hoppers, dump, ore and coke	299,425
Tank	7,250
Flat, log and miscellaneous	4,375

Steel underframe.

Box	125,403
Refrigerator	1,821
Stock and coke	16,797
Gondolas, hoppers, ballast, ore and dump	75,463
Flat	21,139
Miscellaneous	1,214

To these numbers must be added the cars built by the smaller companies, as well as those built by the various railroad companies at their own shops. It is estimated, from the data available, that there are in use on American railroads, a little over a half-million steel and steel underframe cars, or about 20 to 22 per cent of the freight carrying cars in use.

So many different kinds and designs of each kind of steel and steel underframe cars have been built and placed in service, that in this report the writer will only submit the illustrations shown in figures 6 to 20 as representing some of the kinds and designs used by the various railroads in America and give data somewhat more complete covering the cars of the Pennsylvania Railroad System, with which he is connected.

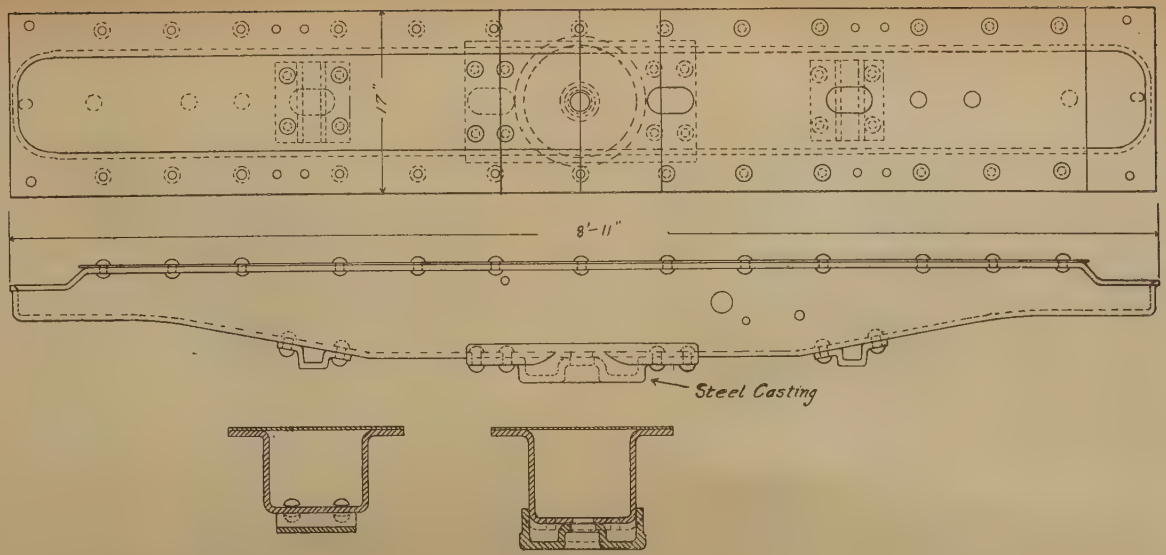
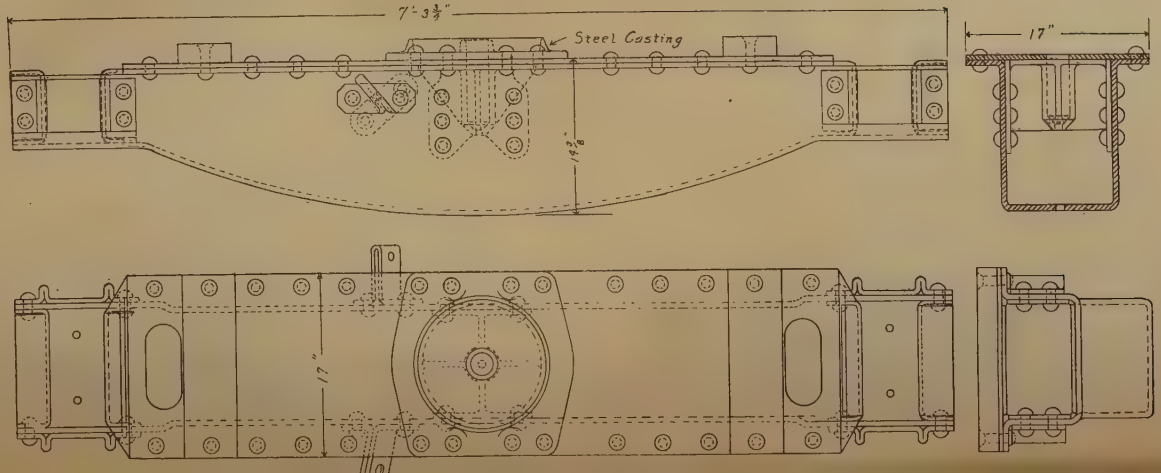


Fig. 4.



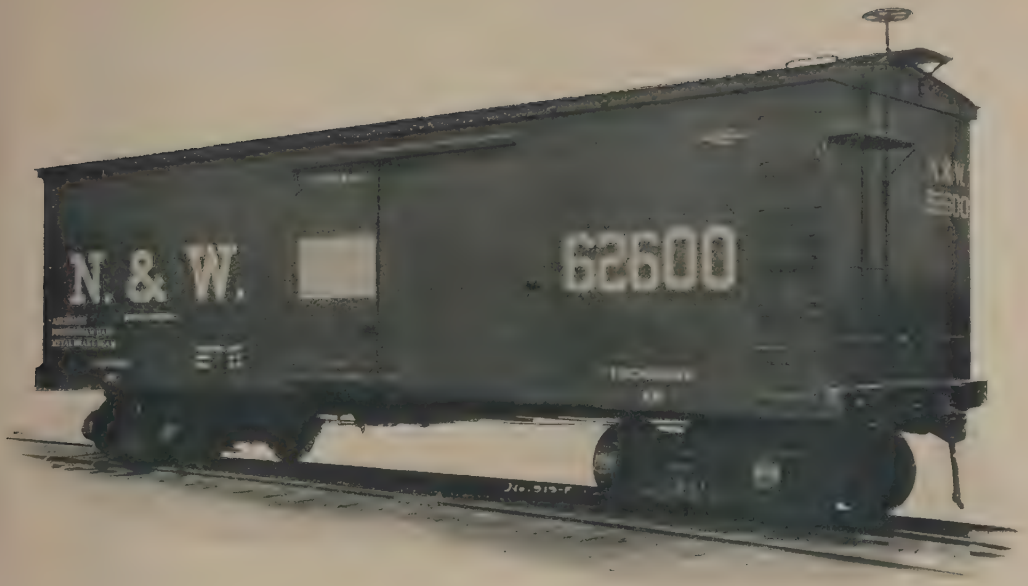


Fig. 6. — Steel frame box car. — Rated capacity : 80,000 pounds.

General dimensions	
Height from rail to top of brake mast	14 ft. 0 1/4 in.
— of eaves	12 ft. 3 1/4 in.
— under car lines	8 ft. 0 in.
— of door openings	6 ft. 10 in.
— of floor from rail	4 ft. 0 in.
Length over end sills	38 ft. 3 in.
— inside	36 ft. 0 1/8 in.
Width at eaves	9 ft. 11 1/4 in.
Width over all	9 ft. 11 3/4 in.
— inside	8 ft. 6 1/8 in.
— of door openings	5 ft. 6 in.

General information :	
Weight of body including underframe	23,930 lb.
— of trucks	14,970 lb.
Total weight	38,900 lb.
Maximum capacity	88,000 lb.

The above represents a type of box car with steel underframe and steel upper framing.

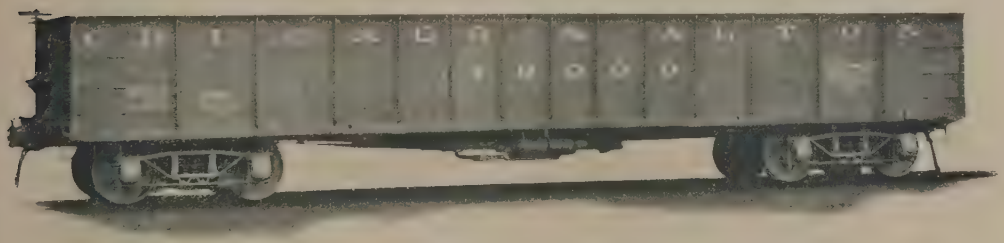


Fig. 7. — Steel flat bottom gondola car. — Rated capacity : 100,000 pounds.

General dimensions :	
Height from rail to top of brake mast	8 ft. 2 3/8 in.
— — — of body	7 ft. 8 1/4 in.
— from floor to top of body	4 ft. 2 in.
Length over end sills	43 ft. 3 in.
— inside of body	41 ft. 9 in.
Width over side stakes	10 ft. 0 3/8 in.
— inside of body	9 ft. 4 7/8 in.

General information :	
Cubic contents level	1,636 cubic feet.
— — 10 inches average heap	1,953 — —
Dead weight of body	20,510 lb.
— — of trucks	15,330 lb.
Total dead weight	35,840 lb.
Maximum load	110,000 lb.

Ratio of paying freight to total weight of car when loaded 75·4 per cent.

*

Fig. 8. — Steel underframe box car. — Rated capacity : 80,000 pounds.

General dimensions	
Height from rail to top of brake mast	13 ft. 10 in.
— at eaves	12 ft. 6 5/8 in.
— under car lines	8 ft. 0 in.
— of door openings	7 ft. 9 in.
— of floor from rail	4 ft. 0 in.
Length over end sills	38 ft. 6 in.
— inside	36 ft. 0 in.
Width at eaves	9 ft. 7 in.
Width over side sills	9 ft. 1 5/8 in.
— inside	8 ft. 6 in.
— of door openings	6 ft. 0 in.
General information :	
Weight of body including underframe	25,370 lb.
— of trucks	14,030 lb.
Total weight	39,400 lb.
Maximum capacity	88,000 lb.

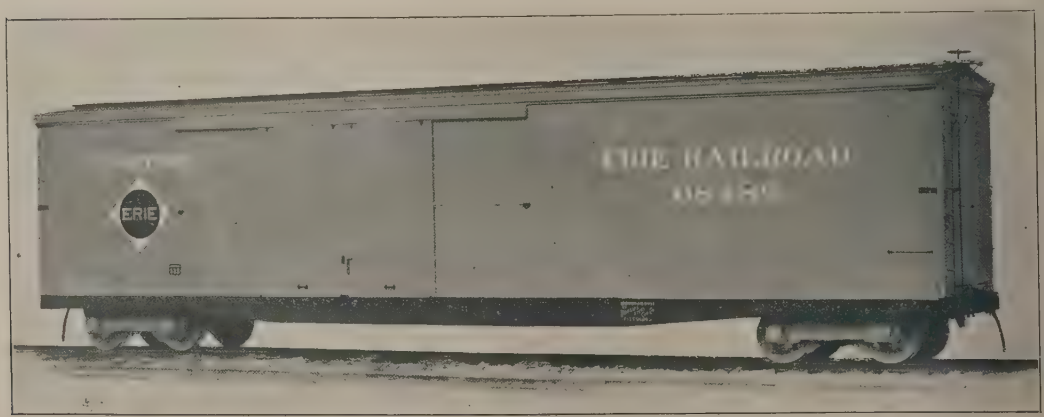


Fig. 9. — Steel underframe furniture car. — Rated capacity : 60,000 pounds.

General dimensions :	
Height from rail to top of brake mast	14 ft. 8 in.
— — to eaves	13 ft. 4 in.
— under car lines	9 ft. 5 3/8 in.
— of door openings	8 ft. 7 7/8 in.
— from rail to floor	3 ft. 6 1/4 in.
Length over end sills	51 ft. 9 3/4 in.
— inside	50 ft. 2 1/4 in.
Width at eaves	9 ft. 10 1/4 in.
Width over side sills	9 ft. 4 in.
— inside	8 ft. 9 1/4 in.
— of door openings	10 ft. 0 in.
General information :	
Dead weight of body	31,610 lb.
— — of trucks	12,260 lb.
Total dead weight	43,900 lb.
Maximum capacity	66,000 lb.

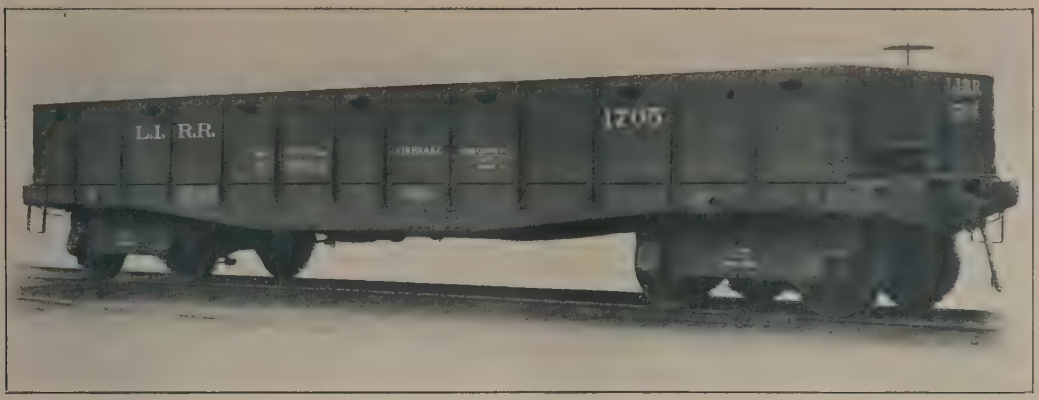


Fig. 10. — Composite flat bottom gondola car. — Rated capacity : 80,000 pounds.

General dimensions :	
Height from rail to top of brake mast	7 ft. 9 1/4 in.
— — — of body	7 ft. 0 1/4 in.
— of sides from floor	3 ft. 0 in.
Length over end sills	37 ft. 10 1/2 in.
— inside of body	36 ft. 0 in.
Width over stake pockets	9 ft. 10 in.
— inside of body	8 ft. 7 7/8 in.
General information :	
Cubic contents level	933 cubic feet.
Cubic contents with 10 inches average heap	1,192 cubic feet.
Dead weight of body	22,562 lb.
— — of trucks	14,638 lb.
Total dead weight.	37,200 lb.
Maximum load uniformly distributed	88,000 lb.
— — concentrated half way between center of car and bolster.	60,000 lb.
Ratio of paying freight to total weight of car when loaded	70·3 per cent.

This is a special type of car, designed for carrying concentrated lo ds of machinery, structural material, etc., which explains the low ratio of paying freight.

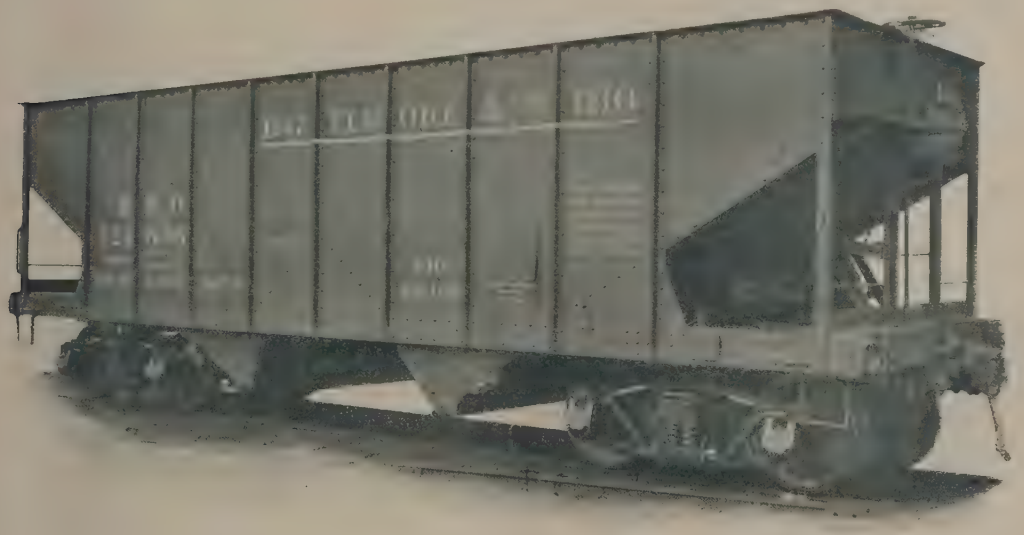


Fig. 11. — All-steel center dumping car. — Rated capacity : 100,000 lb.

General dimensions :	
Height from top of rail to top of brake mast	11 ft. 3 5/8 in.
— — — — of body	10 ft. 7 3/4 in.
Length over end sills	33 ft.
— inside of body	31 ft. 6 in.
— of drop door openings in clear at bottom	2 ft. 7 3/4 in.
Width over side stakes.	9 ft. 11 in.
— inside of body	9 ft. 4 in.
— of drop door openings in clear	2 ft. 6 in.
General information :	
Cubic contents, level	1,790 cubic feet.
— — 10 inches average heap	2,035 — —
Dead weight of body	26,770 lb.
— — of trucks	16,830 lb.
Total dead weight.	43,600 lb.
Maximum load	110,000 lb.
Ratio of paying freight to total weight of car when loaded	71·6 per cent.

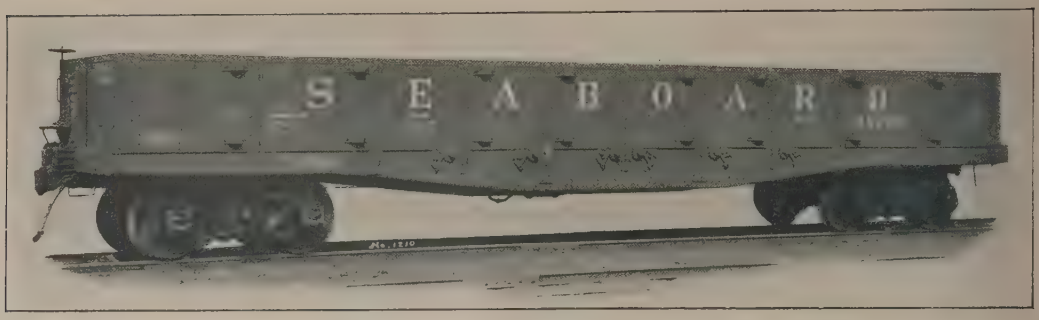


Fig. 12. — Composite flat bottom gondola car with flush drop doors. — Rated capacity : 80,000 pounds.

General dimensions :	
Height of sides from rail.	8 ft. 0 3/8 in.
— — — floor	4 ft. 0 3/8 in.
Length over end sills.	39 ft. 3 1/2 in.
— inside of body	37 ft. 6 in.
— of door openings.	2 ft. 4 in.
Width of door openings	2 ft. 9 in.
— of body over side stakes	9 ft. 7 1/2 in.
— of body inside.	8 ft. 7 in.
Size of journals.	5 × 9 in.

General information :	
Cubic contents level.	1,297 cubic feet.
— — 10 inches heap	1,566 — —
Dead weight of body	22,610 lb.
— — of trucks	14,090 lb.
Total dead weight.	36,700 lb.
Maximum load	88,000 lb.
Ratio of paying freight to total weight of car when loaded.	70·5 per cent.

This car has pressed steel underframe with wooden top and floor. The floor has twelve flush drop doors between the trucks; six doors on each side of the center sills. Practically 50 per cent of a lading of coal may be discharged through these doors without shovelling. A greater or less number of doors may be used, and the underframe may be built of structural material if desired.

Fig. 13. — All-steel self-clearing side dumping coke car. — Rated capacity : 100,000 lb.

General dimensions :	
Height from top of rail to top of brake mast	12 ft. 7 in.
— from rail to top of body	12 ft. 0 in.
Length over end sills	41 ft. 9 in.
— inside of body	40 ft. 5 in.
— of drop doors in clear	23 ft. 0 in.
Width over side stakes	10 ft. 1 in.
— inside of body	9 ft. 7 in.
— of drop doors in clear	4 ft. 0 in.

General information :	
Cubic contents, level	2,945 cubic feet.
— — with 10 inches average heap	3,268 — —
Dead weight of body	31,630 lb.
— — of trucks.	15,870 lb.
Total dead weight.	47,500 lb.
Maximum load	110,000 lb.
Ratio of paying freight to total weight of car when loaded	69·9 per cent.

This type of car was specially designed for carrying coke and to be self-clearing. It will hold 101,600 pounds of coke at 32 pounds per cubic foot, with a 10-inch average heap. It is equally suitable for other ladings usually carried in dump cars, such as coal, etc., but it must not be filled so as to have more than 110,000 pounds. Cars filled with coke have been unloaded in most unfavourable weather in three minutes without shovelling. Doors are hung vertically, two on each side and may be operated simultaneously from ends of car.

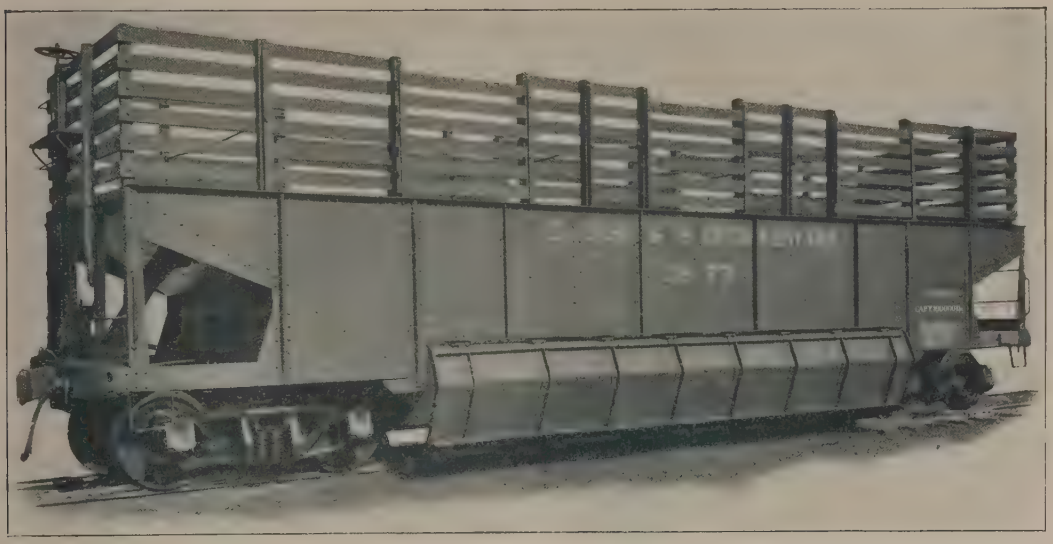


Fig. 14. — Steel side dump coke car with rack. — Rated capacity: 100,000 pounds.

General dimensions	
Height from rail to top of brake mast	13 ft. 0 3/4 in.
— — — of coke racks	12 ft. 6 in.
— — — of steel sides	8 ft. 3 in.
Length over end sills	41 ft. 4 in.
— inside of body	40 ft. 0 in.
— of door openings	22 ft. 7 in.
Width over all	10 ft. 2 1/2 in.
— inside of body	9 ft. 5 1/4 in.
— of door openings	2 ft. 5 in.

General information:	
Cubic contents, level with racks	3,425 cubic feet.
— — with 10 inch average heap	3,745 — —
Dead weight of body	29,350 lb.
— — of trucks	15,750 lb.
Total dead weight	45,600 lb.
Maximum load	110,000 lb.
Ratio of paying freight to total weight of car when loaded	70·8 per cent.

This type of car was specially designed for the carrying of coke, and to dump the lading to the sides. It will hold about 110,000 pounds of coke, and is practically self-clearing. While intended for transportation of coke it is also suitable for other ladings usually carried in dump cars, such as coal, ashes, etc., but it must not be filled so as to have more than 110,000 pounds of lading. Doors are operated from the ends of the car. The cars are constructed almost entirely of pressed steel, which gives lightness consistent with strength but the design may be made from plate and rolled shapes if desired.

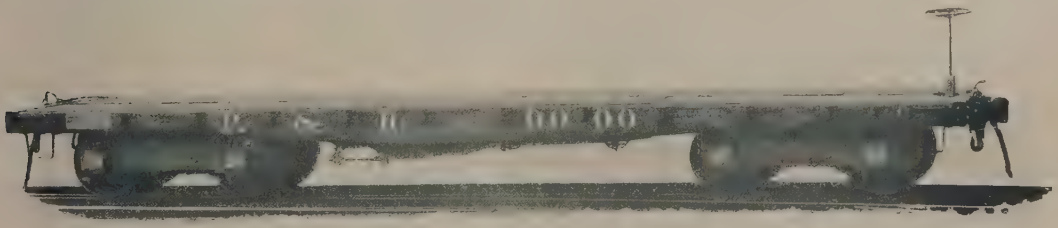


Fig. 15. — Steel flat car (with steel floor). — Rated capacity: 100,000 pounds.

General dimensions:	
Height from top of rail to top of brake mast	6 ft. 6 1/4 in.
— — — of floor	3 ft. 6 1/4 in.
Length over end sills	35 ft. 6 in.
Width over stake pockets	10 ft. 1 3/4 in.
— side sills and floor	9 ft. 6 in.

General information:	
Dead weight of body	13,610 lb.

General information:	
Dead weight of body	13,610 lb.
Dead weight of trucks	14,640 lb.
Total dead weight	28,250 lb.
Maximum load uniformly distributed	110,000 lb.
— — concentrated within 5 feet length near center	50,000 lb.
Ratio of paying freight to total weight of car when loaded	79·5 per cent.

Fig. 16. — All-steel center dumping ore car. — Rated capacity : 100,000 pounds.

General dimensions:		General information	
Height from top of rail to top of brake mast. . .	9 ft. 6 1/2 in.	Cubic contents, level	602 cubic feet.
— — — — of body . . .	9 ft. 0 in.	— — 10 inch. average heap.	827 — —
Length over end sills	22 ft. 0 1/4 in.	Dead weight of body	16,000 lb.
— inside of body	20 ft. 4 in.	— — of trucks	16,000 lb.
— of door opening	6 ft. 8 in.	Total dead weight. . .	32,000 lb.
Width over side stakes	8 ft. 6 in.	Maximum load	110,000 lb.
— inside of body	7 ft. 11 1/2.	Ratio of paying freight to total weight of car when	
— of door opening	3 ft. 6 in.	loaded	77·4 per cent.

These cars are practically self-clearing. There are four doors, operated in pairs by chains located outside of the lading at the ends of each pair or doors. The gearing is so constructed that abnormal twisting of chain shaft cannot take place, and the doors close evenly at both sides.

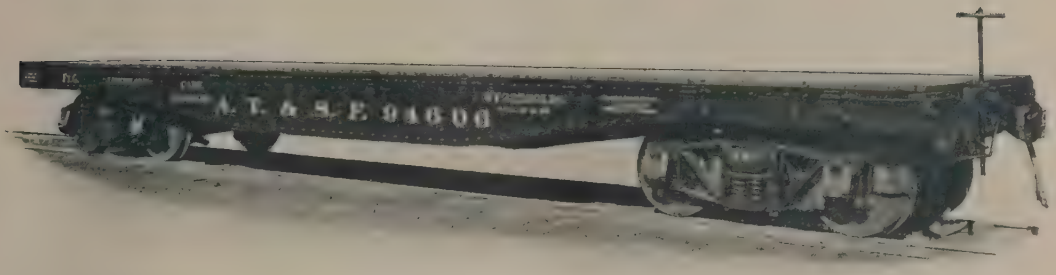


Fig. 17. — Steel underframe flat car. — Rated capacity : 80,000 pounds.

General dimensions	
Height from rail to top of brake mast	5 ft. 8 3/8 in.
— — — of floor	3 ft. 11 1/16 in.
Length over end sills	40 ft. 4 in.
Width over floor	8 ft. 10 in.
— over stake pockets	9 ft. 6 3/8 in.

General information:	
Dead weight of body	17,980 lb.
— — trucks	14,220 lb.
Total dead weight	32,200 lb.
Maximum capacity	88,000 lb.
Ratio of paying freight to total weight of car when loaded	73·3 per cent.

This car has center and side sills made of plates and angles, and diaphragms of pressed steel. The rated capacity is 80,000 pounds and the underframe is designed to carry a concentrated load at the center on a five foot base of 90,000 pounds. The location of diaphragms and stake pockets is such that removable sides for use of unloading machines may be applied. The hand brake mast is of the tilting kind, that it may be turned down when in the way of a lading without losing the use of the hand brake.

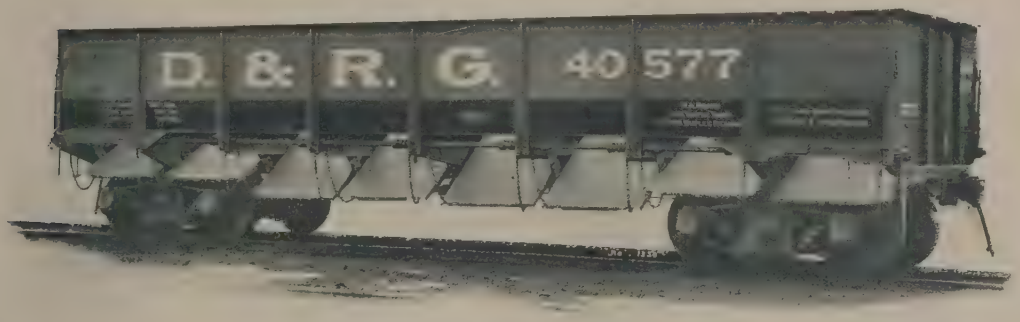


Fig. 18. — All-steel general service gondola car (With 16 drop doors). — Rated capacity : 100,000 pounds.

General dimensions :	
Width of doors in clear	3 ft. 11 1/8 in.
Length of doors in clear	3 ft. 10 1/2 in.
Height of door opening between trucks	2 ft. 3 in.
— — over trucks	1 ft. 6 in.
— from rail to top of brake mast	9 ft. 0 1/4 in.
— — — of body	8 ft. 6 1/4 in.
— from floor to top of body	4 ft. 2 in.
Length over end sills	37 ft. 0 in.
— inside of body	36 ft. 6 in.
Width over side stakes	10 ft. 2 1/4 in.
Width inside of body	9 ft. 6 3/4 in.

General information	
Cubic contents, level	1,402 cubic feet.
— — 10 inches average heap	1,689 — —
Dead weight of body	24,550 lb.
— — of trucks	15,950 lb.
Total dead weight	40,500 lb.
Maximum load	110,000 lb.
Ratio of paying freight to total weight of car when loaded	73·2 per cent.

The car illustrated above is of the general service type and may be used as an ordinary gondola car or a side dump car, which makes it suitable for all kinds of lading usually carried in gondola car or hopper cars.

Cars are built with drop doors throughout their length as shown in the cut, or with the floor solid between the ends of the car and the bolsters, as may be desired. With doors throughout the length of the car practically the whole of a lading of coke or coal can be discharged and the doors closed again in 4 minutes. Doors are operated by means of the creeping shaft device, which has proved superior to all other devices for similar purposes, and when the doors are closed they cannot be accidently opened.

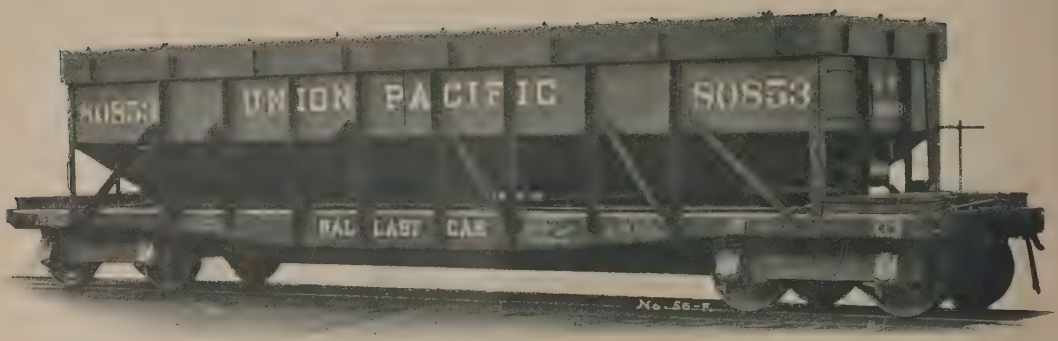


Fig. 19. — Ballast car. — Rated capacity : 100,000 pounds.

General dimensions :

Height from rail to top of body	8 ft. 3 in.
Length over end sills	40 ft. 6 in.
— inside of body	32 ft. 7 1/4 in.
— of drop doors in clear	23 ft. 10 3/4 in.
Width over side stakes	9 ft. 4 in.
— inside of body	8 ft. 8 1/2 in.
— of drop doors in clear	1 ft. 2 15/16 in.

General information :

Cubic contents, level	1,250 cubic feet.
— contents with 10 inches average heap	1,487 cubic feet.
Dead weight of body	21,300 lb.
— — of trucks	15,030 lb.
Total dead weight	36,330 lb.
Maximum load	110,000 lb.
Ratio of paying freight to total weight of car when loaded	75 per cent.

For light ballast material, cars may be equipped with upper extension boards to give full load capacity.

Fig. 20. — Steel transportation tank car. — Rated capacity : 80,000 pounds, 8,000 gallons.

General dimensions :

Height from top of rail to top of brake mast	6 ft. 2 3/8 in.
— — — — of running board	3 ft. 6 3/4 in.
— — — to center of tank	7 ft. 5 15/16 in.
Diameter of tank at center inside	7 ft. 2 in.
Length center to center of outside rivets at head	26 ft. 4 in.
Width over side sills	9 ft. 0 in.
Width over all	10 ft. 0 in.

General information :

Dead weight of tank	11,472 lb.
— — of underframe, straps, bands, etc.	13,841 lb.
— — of trucks	14,587 lb.
Total dead weight	39,900 lb.

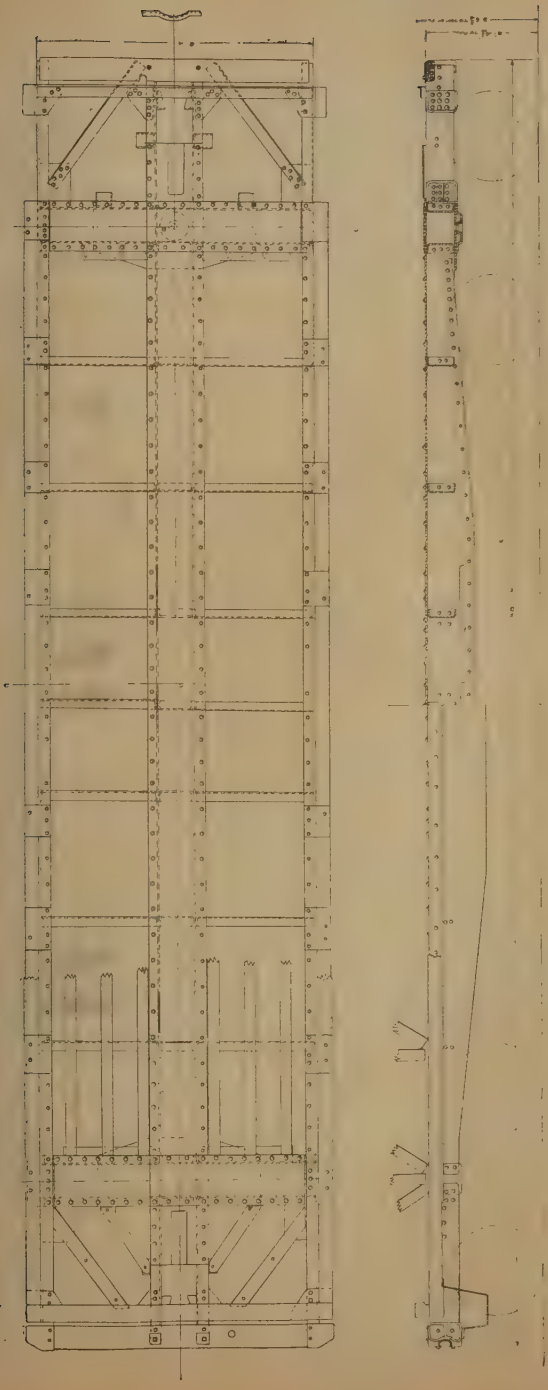


Fig. 21.

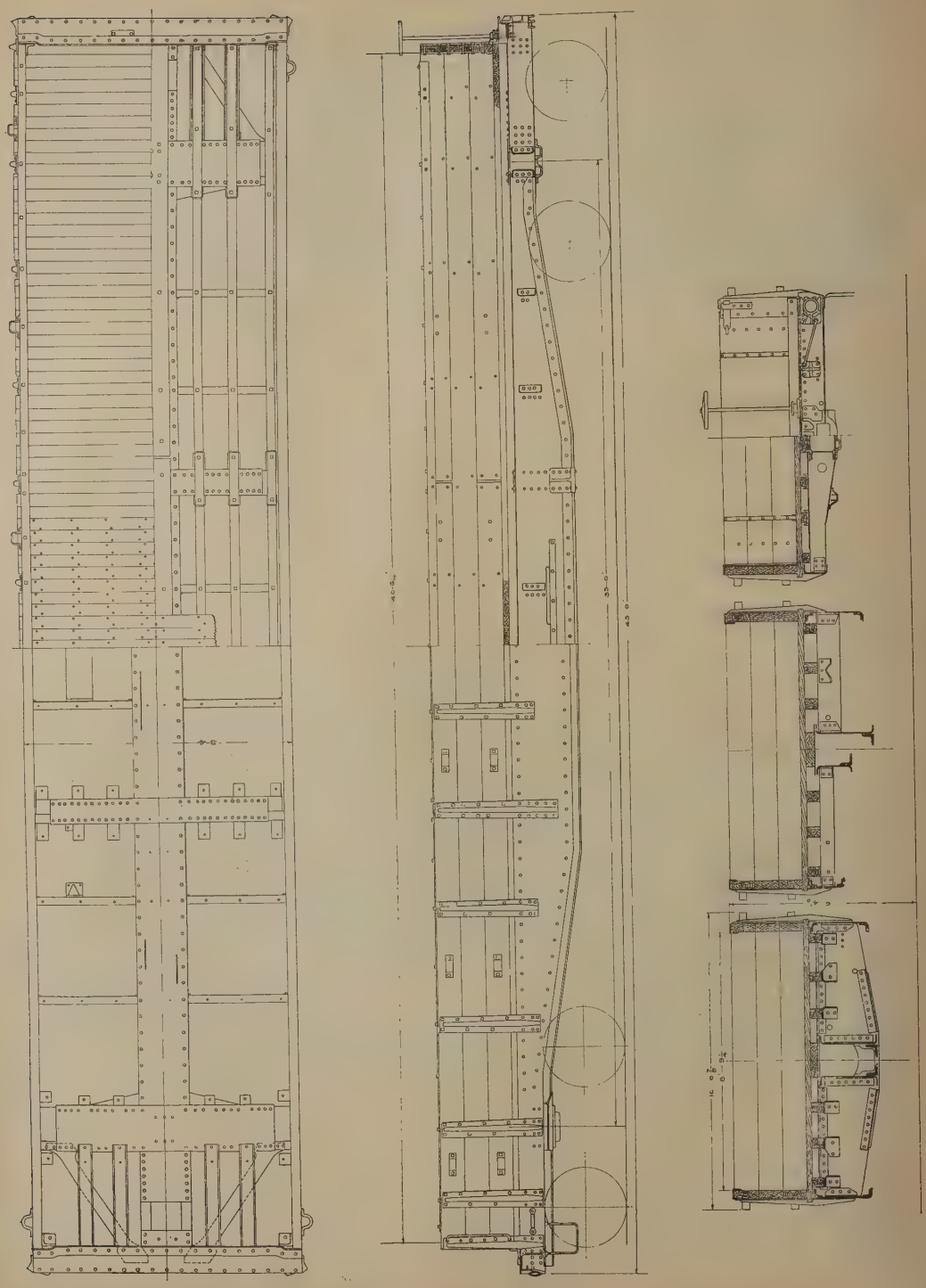


Fig. 22.

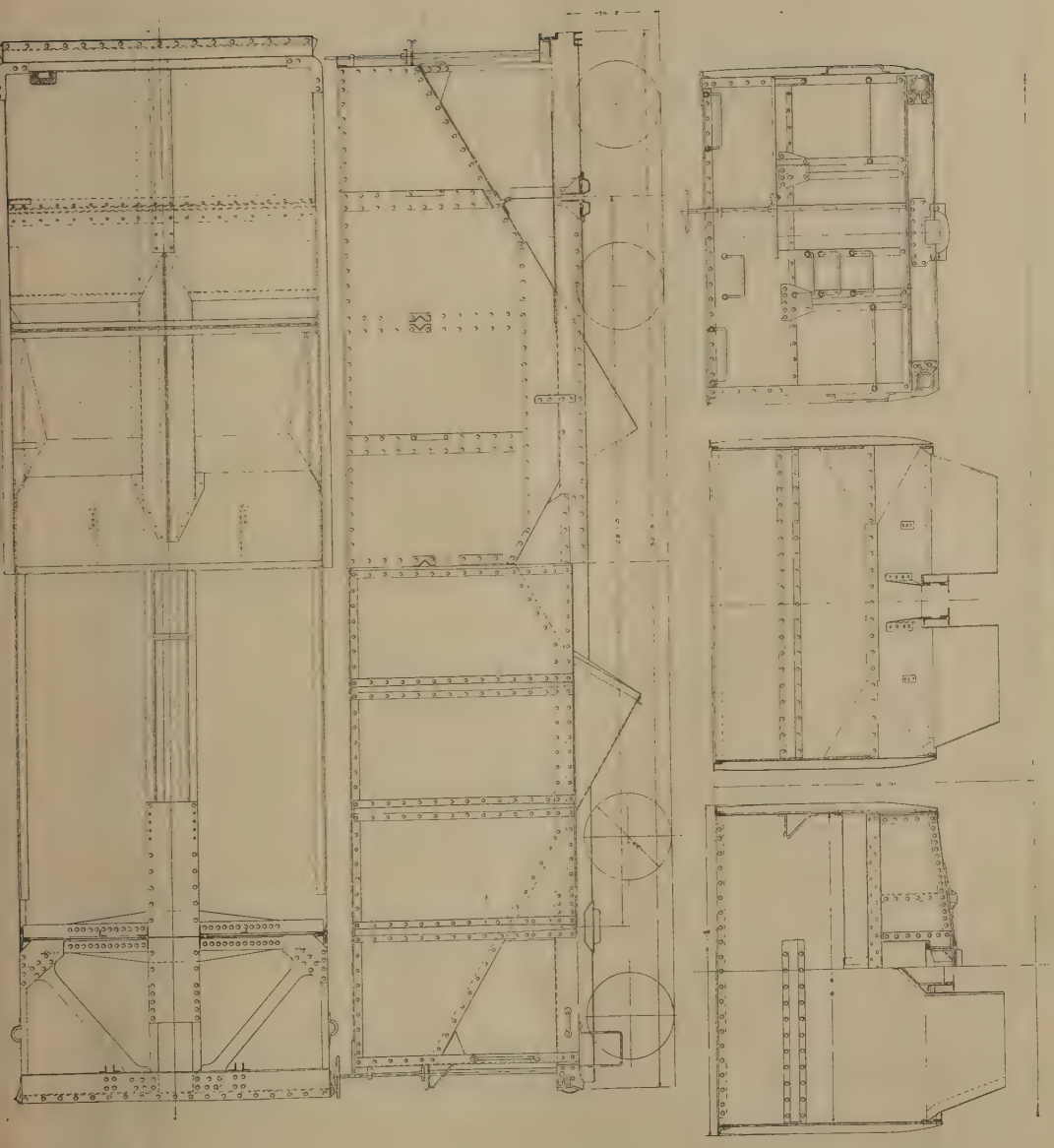


Fig. 23.

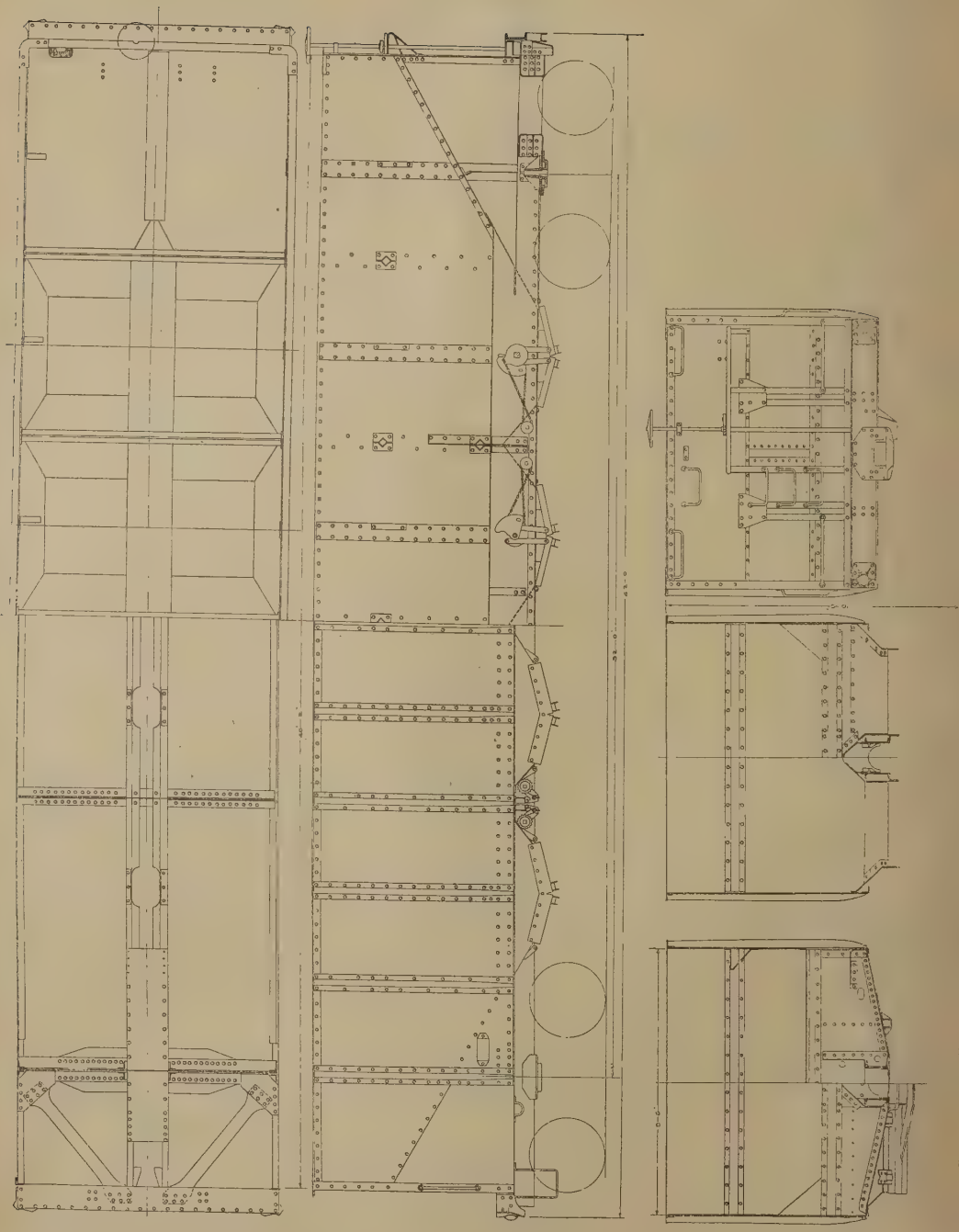


Fig. 24.

At the present time, the freight carrying equipment of the Pennsylvania System consists of 243,809 cars, divided as follows :

—	Wood.	Steel Underframe.	Steel.	Total.
Box	47,963	31,362	...	79,325
Refrigerator	2,795	2,724	...	5,519
Stock	3,150	1,659	...	4,809
Gondola	30,655	17,917	24,522	73,094
Hopper	17,591	...	39,596	57,187
Coke	7,470	...	6,822	14,292
Flat	1,701	...	3,526	5,227
Tank	525	...	...	525
Lime	49	...	...	49
Charcoal	65	...	...	65
Dump	571	...	...	571
Cabin	3,146	...	...	3,146
Total.	115,681	53,662	74,466	243,809

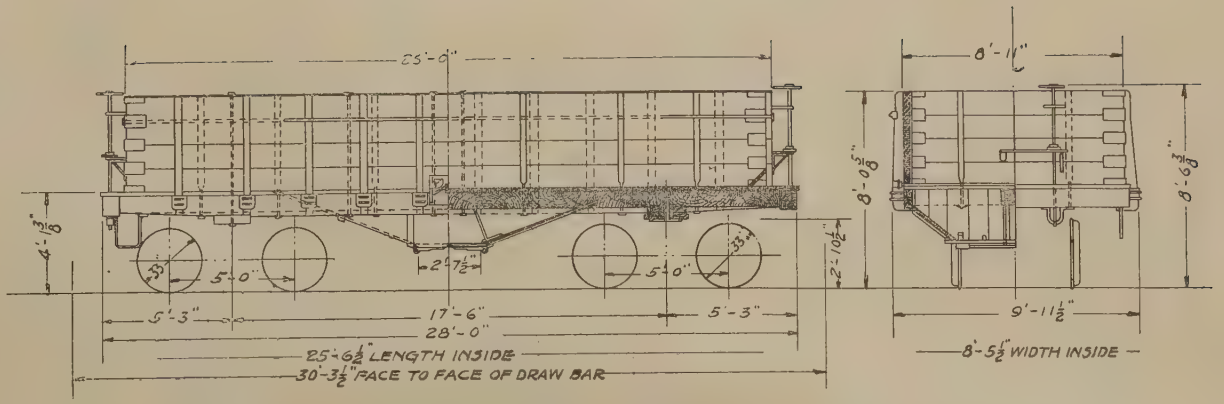
The type, design and general dimensions of some of these cars is shown by the following diagrams figs. 25 to 39 these, with the photographic illustrations already referred to, will serve to give the reader a very comprehensive idea of the freight car construction which is used in America, as the cars of all the roads approach closely in design and dimensions to the data given above.

As examples of detail construction, the following drawings are submitted : Figure 21, general plan and cross sections of steel underframe, for box, stock and refrigerator cars of 100,000 pounds nominal capacity. The superstructures used with this underframe being of wooden construction.

Figure 22, general plan and cross section of steel underframe, for gondola and flat cars of 100,000 pounds capacity. The figure shows a car provided with wooden floor and sides, and when so arranged is intended primarily for transportation of heavy steel girders, bridge and building material, iron pipe and heavy machinery.

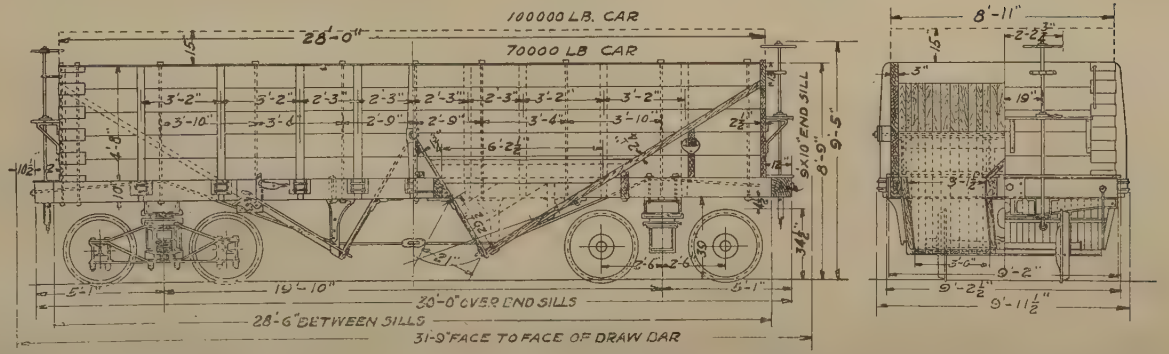
Figure 23, general plan and cross sections of an all-steel hopper car of the self-cleaning type of 100,000 pounds capacity. Cars of this type are used principally for the transportation of iron ore, coal, limestone, and similar heavy materials — the entire lading can be discharged through the bottom doors. Cars of this general design are largely used by all railroads having heavy mineral traffic.

Figure 24, general plan and cross sections of a car of all-steel construction,



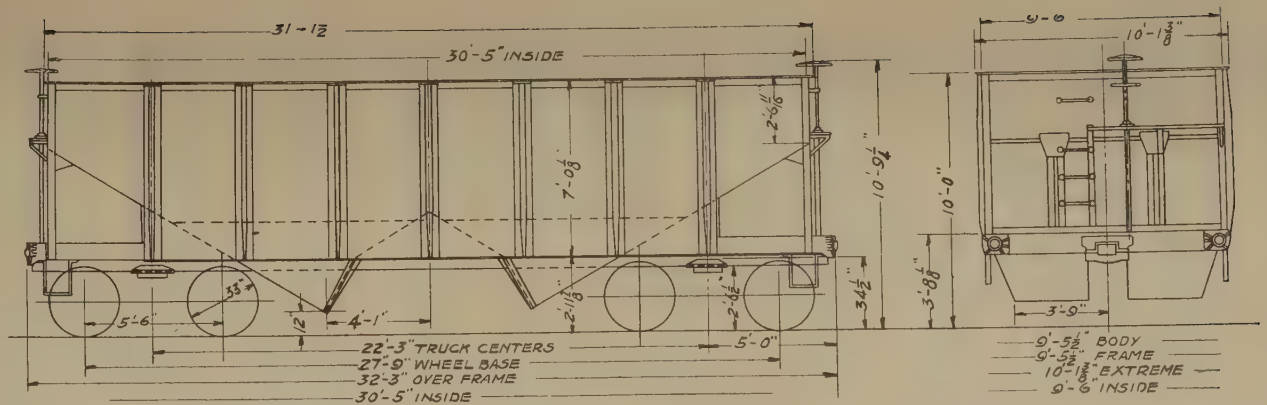
Coal capacity in cubic feet:	Box	966.5	Capacity	60,000 lb.
	Heap	162	Weight	237,000 lb.
	Total	1,128.5		

Fig. 25.



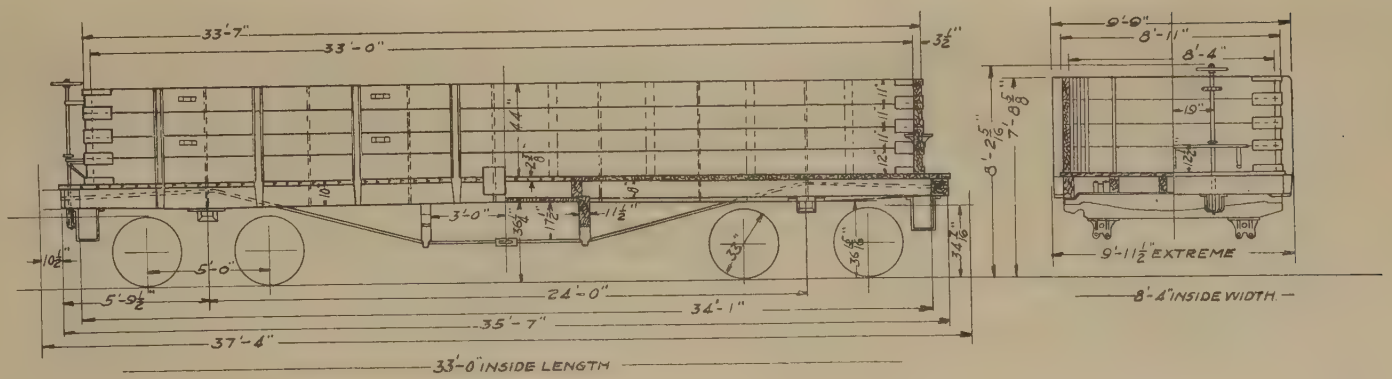
70,000 lb. car	Cubical contents	926 cubic feet.	Weight of car	36,200 lb. With 4 ft. 8 in. sides and iron on long slope.
	Capacity	70,000 lb.	Weight of truck	5,300 lb.
100,000 lb. car	Cubical contents	1,221 cubic feet.	Weight of car	40,200 lb. With 5 ft. 11 in. sides and iron on long slope.
	Capacity	100,000 lb.	Weight of truck	7,900 lb.
			Weight of car	39,900 lb. With 5 ft. 11 in. sides and no iron on long slope.

Fig. 26.



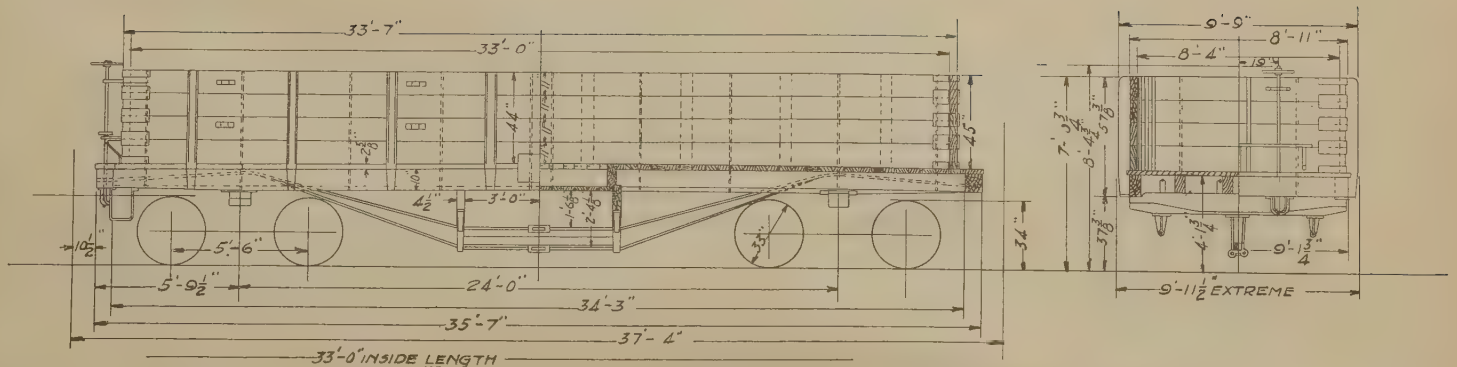
Cubical contents.	1,633 cubic feet.	Weight of car.	39,000 lb.
Capacity	100,000 lb.	Weight of truck	7,900 lb.

Fig. 27.



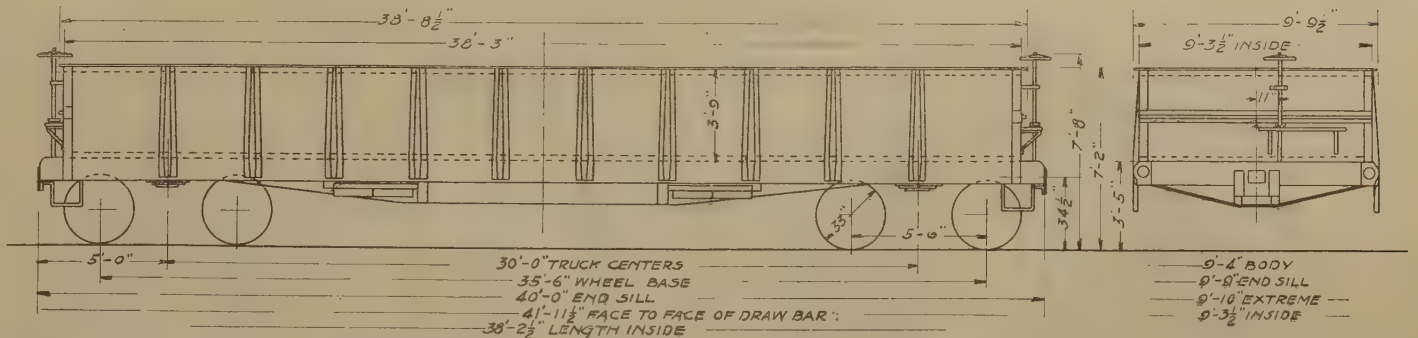
Cubical contents. 1,021 cubic feet. | Floor area . . . 275 square feet. | Weight of car . . . . 28,700 lb. | Weight of truck. . . . 5,300 lb. | Capacity . . . . . 60,000 lb.

Fig. 28.



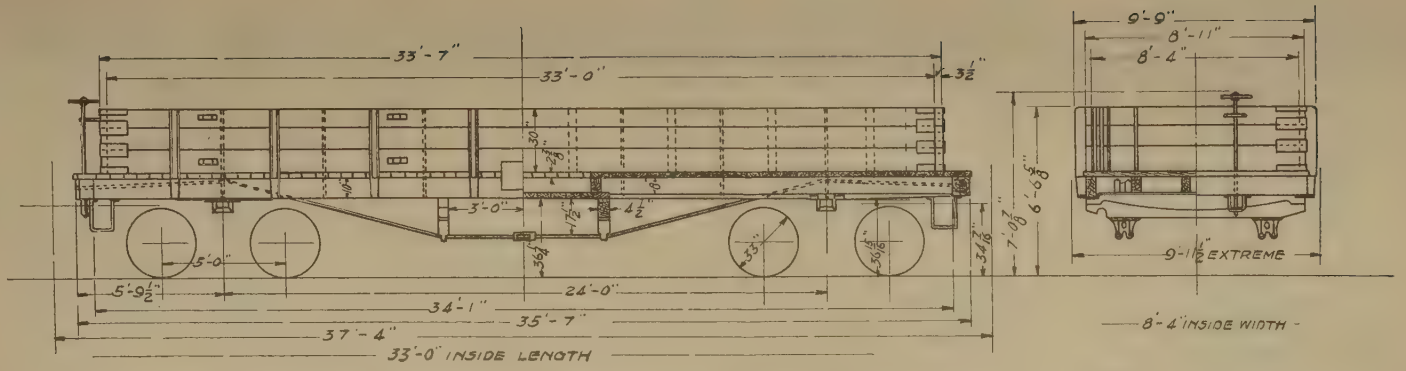
Floor area . . 275 square feet. | Cubical contents . 1,038 cubic feet. | Weight of car . . . 32,500 lb. | Weight of truck . . . 7,300 lb. | Capacity . . . . 80,000 lb.

Fig. 29.



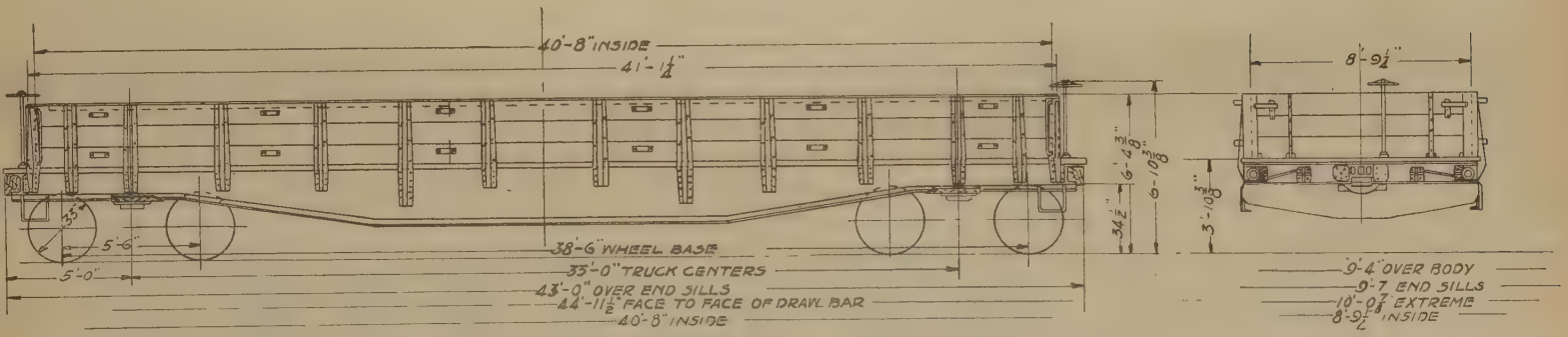
Floor area . . 355 square feet. | Cubical contents. 1,331 cubic feet. | Weight of car . . . 38,500 lb. | Weight of truck. . . 7,900 lb. | Capacity . . . . 100,000 lb.

Fig. 30.



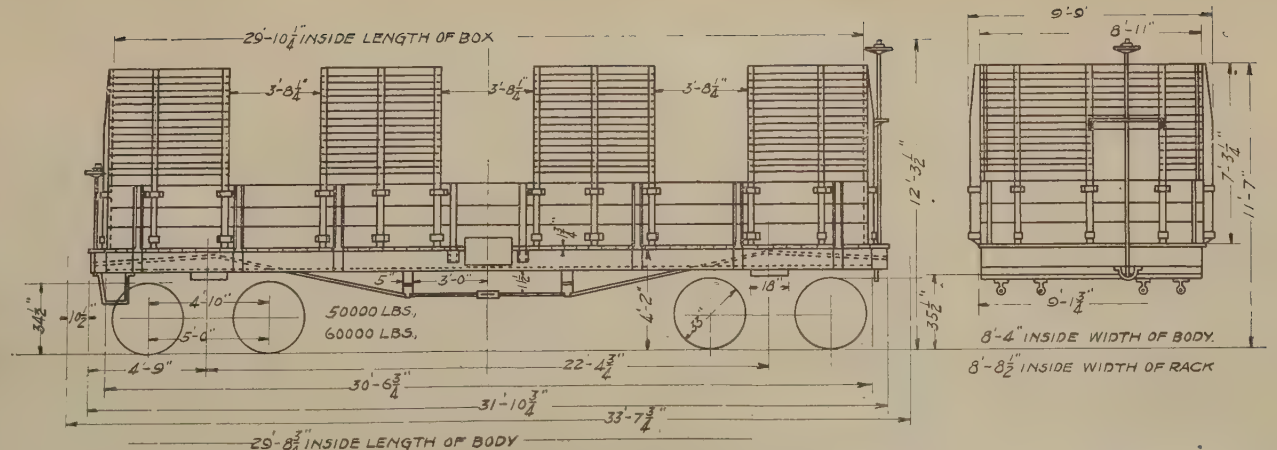
Floor area . . 275 square feet. | Cubical contents . 703 cubic feet. | Weight of car . . . . 26,800 lb. | Weight of truck. . . 5,800 lb. | Capacity. . . . . 60,000 lb.

Fig. 31.



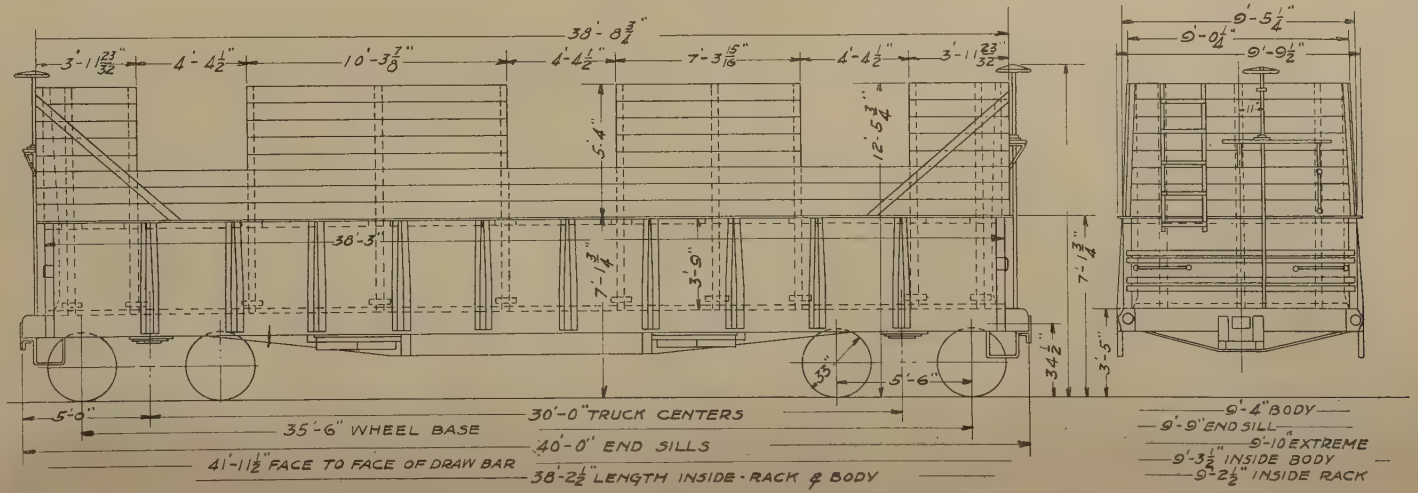
Floor area	356·6 square feet.	Cubical contents of heap	356·6 cubic feet.	Weight of truck	7,900 lb.
Cubical contents of body	891·5 cubic feet.	Weight of car	46,700 lb.	Capacity	100,000 lb.

Fig. 32.

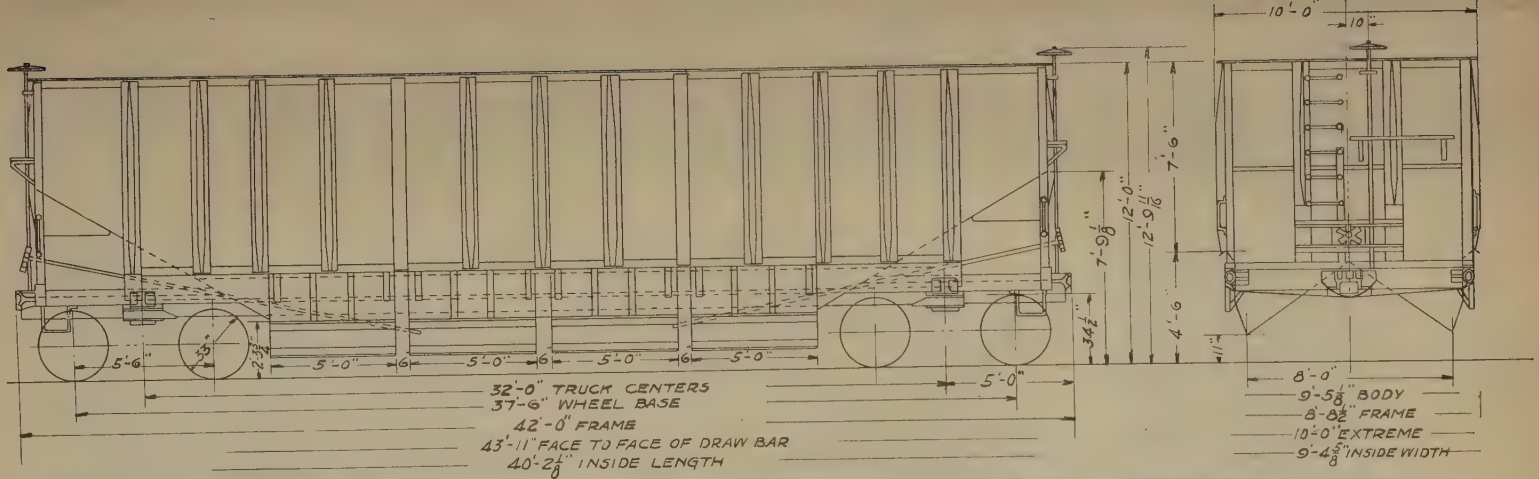


Floor area.	247 square feet.	Capacity	50,000 lb.	Weight of car (50,000) . . .	25,700 lb.	Weight of truck (50,000) . . .	4,600 lb.
Cubical contents . .	1,857 cubic feet.		60,000 lb.	Weight of car (60,000) . . .	30,800 lb.	Weight of truck (60,000) . . .	5,850 lb.

Fig. 33.

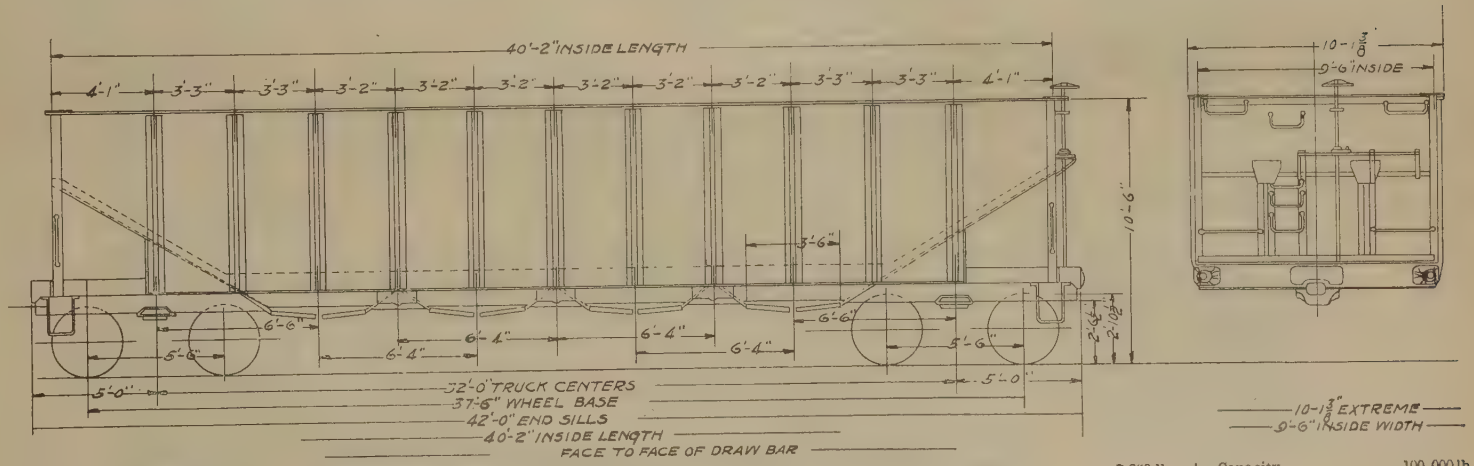


Floor area. .	355 square feet.	Cubical contents.	3,192 cubic feet.	Weight of car . .	44,400 lb.	Weight of truck. . .	7,900 lb.	Capacity . . .	100,000 lb.



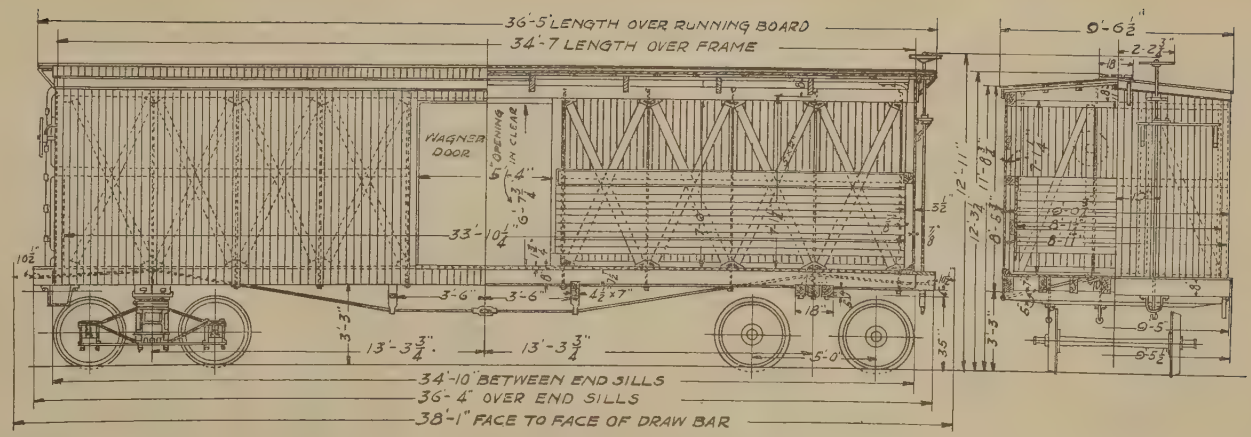
Cubical contents . 3,123·5 cubic feet. | Capacity . . . 100,000 cubic feet. | Weight of car . . . 52,000 lb. | Weight of truck . . . 7,900 lb.

Fig. 35.



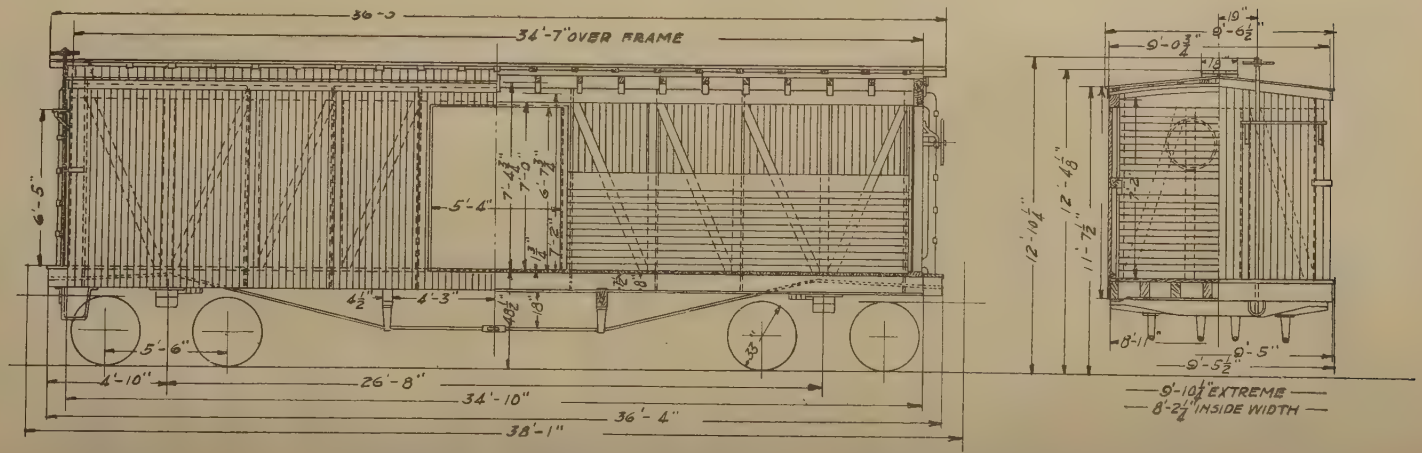
Floor area . . 381·5 square feet. | Cubical contents. 2,564 cubic feet. | Weight of car . . . 45,500 lb. | Weight of truck . . . 7,900 lb. | Capacity . . . . . 100,000 lb.

Fig. 36.

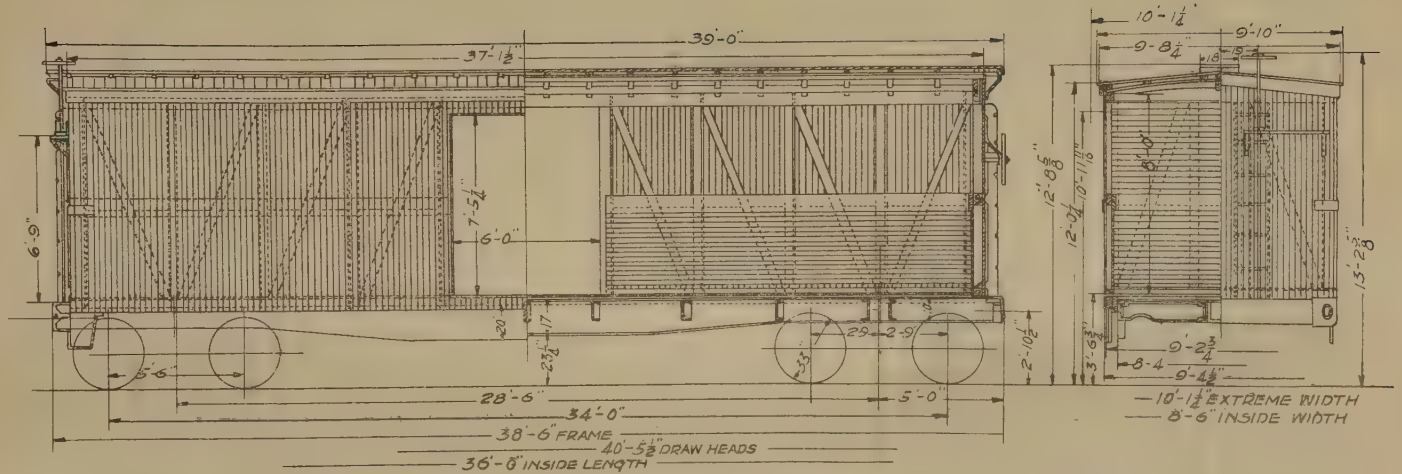


Floor area	274 square feet.	Capacity	60,000 lb.	Weight of truck	5,850 lb.
Cubical contents	1,947 cubic feet.	Weight of car	30,200 lb.	Iron truck.	

Fig. 37.



Floor area	276 square feet.	Capacity	80,000 lb.	Weight of truck (60,000 lb. capacity)	5,900 lb.
Cubical contents	2,032 cubic feet.	Weight of car (with 60,000 lb. truck)	33,200 lb.	Weight of truck (80,000 lb. capacity)	7,300 lb.
Capacity	60,000 lb.	Weight of car (with 80,000 lb. truck)	35,000 lb.		



Floor area	306 square feet.	Weight of car	44,300 lb.
Cubical contents	2,448 cubic feet.	Weight of truck	7,900 lb.
	Capacity	100,000 lb.	

Fig. 39.

of 100,000 pounds capacity, especially designed for hauling coke, although suitable for ore, coal, limestone, etc.

In order that the coke may be readily discharged, large area of opening is provided; cars of this type having three sets instead of four sets of doors have been constructed. The available discharge space being about 84 square feet in car having four openings and 72 square feet in cars having three openings.

Quality of steel. — It will be noted from the above that about twelve years ago steel for freight car construction was used only for axles, springs and couplers; and for a comparatively small number of cars for truck frames, body bolsters, truck bolsters and stake pockets, while at the present time steel is used to a greater or less extent for practically all parts that go to make up a car.

Wrought iron is used for brake rods, and brake chain and cast iron or malleable iron for journal boxes and the smaller castings, although in a great many cases steel castings are supplanting wrought, cast and malleable iron.

For the structural shapes and pressed or formed plates, steel of about the following quality is used :

Open hearth steel.

Tensile strength	52,000 to 67,000 lb.
Elongation	29 to 22 per cent.
Phosphorus	Not to exceed 0·05 per cent.

and for steel castings steel meeting the following requirements is deemed suitable :

Tensile strength, about	70,000 lb. to square inch.
Elongation, about	15 per cent.

all castings are to be carefully annealed.

Cost of cars. — It is impossible to give any accurate comparison of the first cost of cars of steel and cars of wooden construction as any steel cars which have been built are of much stronger design and construction than the cars of wooden construction. That is, the cost of exactly equivalent strength is not available. Therefore, part of the higher cost of the steel car is due to increased strength rather than to the change of material. The fluctuation in the price of material also makes variations.

It is safe to assume that cars of all steel construction will cost from 25 to 50 per cent in excess of cars of wooden construction, depending on the difference in the strength of construction permitted.

All steel hopper cars similar to those illustrated in figures 23 and 27 have been built for 900 dollars, while the wooden car illustrated in figure 26 cost about 700 to 750 dollars.

As the available supply of lumber decreases the cost is increased and even at this

date the grade of quality of lumber formerly used in car construction is sold at a price which makes it necessary to lower the grade of lumber used, the cost of the grade which is considered best prohibiting its use.

The difference in price of the steel as compared with the wooden cars will undoubtedly become more favorable to the former, both on account of the increased cost of lumber and the possible decrease in the price of steel, made possible by the rapid developments of the various manufacturing processes involved.

Cost of maintenance. — On the Bessemer and Lake Erie Railroad, where steel cars have been in use since 1897, records have been maintained to ascertain the average cost of maintenance for wooden and steel cars separately. From the Annual Report of this Company your reporter quotes the following :

Average maintenance cost per car per year.

Year.	Wooden cars.	Steel cars.
1905	$71·14	$27·83
1906	94·11	30·74
1907	118·50	39·21
1908	53·06	32·11

The steel cars covered by the above are of the all steel construction. This data is the best available at the present time on the comparative cost of maintenance of cars of wooden and of steel construction, as on many roads separate records of costs of the steel and wooden cars have not been maintained, and on other roads the cars of steel construction have not been in service a sufficient length of time to permit the consideration, as comparative, of such data as has been obtained.

The writers's observations and estimates tend to confirm the figures given above, namely. That the all steel cars can be maintained for about 30 dollars per car per year as compared with 60 dollars per car per year for cars of wooden construction.

Life of steel cars. — Twelve years is, of course, not a sufficient length of time to obtain any data regarding the probable life of the steel cars or steel parts of the composite cars.

Careful inspection of a hopper car used for carrying coal and ore for eleven years fails to give any evidence as to what life may be expected, the deterioration being hardly appreciable.

The cars of wooden construction were frequently damaged in service to such an extent that the expense of restoring them to condition for service was not warranted. With the cars of steel construction very few cars have been damaged to the extent which would make it inadvisable to repair them.

Of the cars of steel and steel underframe construction in the freight carrying equipment of the Pennsylvania Railroad but 18 of the all steel cars and 126 of the steel underframe cars have been destroyed in eleven years, the majority of these

being destroyed on other roads where facilities for repairing had not been provided; during the same period about 20,000 wooden cars were destroyed as a result of being damaged in service.

The number of steel and steel underframe cars destroyed each year was as follows :

YEAR.	Number of cars as on 31 December.		Number of cars destroyed during the year.	
	All steel.	Steel underframe.	All steel.	Steel underframe.
1898	1,371	...	...	...
1899	2,838	3	...	...
1900	4,838	3	...	...
1901	9,119	2,174	...	...
1902	17,660	16,536	1	4
1903	26,331	24,084	3	10
1904	29,129	26,964	9	11
1905	39,460	32,827	1	5
1906	64,531	44,456	...	32
1907	74,582	51,426	2	42
1908	74,814	57,200	2	22
Total.	...	...	18	126

Weight and capacity. — Comparisons of the weight carrying capacity and the cubic capacity of cars of steel construction or having steel underframes; and the same points of cars of wooden construction, with the weight of the vehicle, show considerable advantage in the use of the steel structures.

The data in statement A gives information from this view point regarding the various types of cars already illustrated.

By the use of cars of larger capacity, the proportion of the paying load to the total weight of lading and car is generally increased, and the effect of the use of the heavier cars in service during a term of years is well illustrated by figures 40 and 41, showing the results obtained on a portion of the Pennsylvania Railroad System. Figure 40 shows graphically the average weight per car, capacity per car, paying load per loaded car and paying load per car operated for each year since 1890, compared with the values of these various items during the year 1890 by assuming the values in 1890 as unity. This diagram shows an increase of

Statement A.

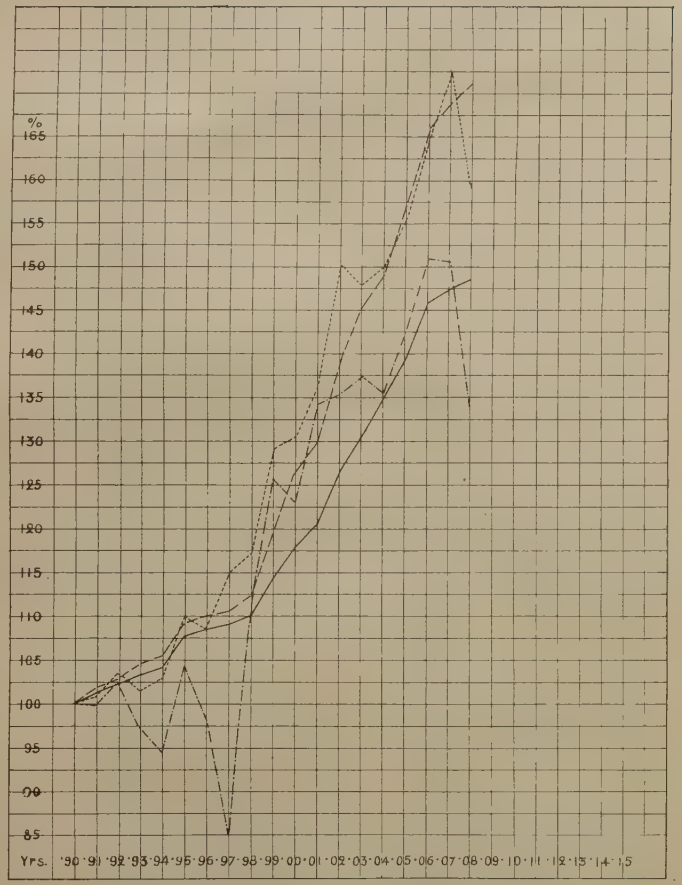
—

Comparative weight and capacity of cars of steel, steel underframe and wooden construction.

(General superintendant M. P., Pittsburgh, 29 July 1909. — General data w. 108.)

Kind.	Material.	Nominal capacity, in lb.	Average weight per car, in lb.	Ratio weight of car to nominal capacity.	Cubic capacity (heap average inche), in cubic feet.	Lading based on cubic capacity coal 52 lb., coke 30 lb. per cubic feet, in lb.	Ratio weight of car to weight of lading, in per cent.	Proportion of paying load to total weight, in per cent.	Maximum load permitted, ore, etc., in lb.	Ratio weight of car to maximum lading, in per cent.	Figure.	Notes.
1	2	3	4	5	6	7	8	9	10	11	12	13
						Coal.						
Hopper.	Wood.	60,000	26,700	44·5	1,128	58,650	45·5	68·7	66,000	40·5	25	
—	—	100,000	40,200	40·2	1,395	72,540	55·5	64·2	110,000	36·7	26	
—	Steel.	100,000	39,000	39·0	1,910	99,320	39·2	71·8	110,000	35·5	27	
—	—	110,000	39,000	35·4	1,910	99,320	39·2	71·8	121,000	32·2	27	(1)
Gondola.	Wood.	60,000	28,700	47·8	1,227	63,800	45·0	31·0	66,000	43·5	28	(2)
—	—	80,000	33,000	41·2	1,244	64,700	51·0	33·8	88,000	37·5	29	
—	Steel.	100,000	40,220	40·2	1,597	83,044	48·5	32·7	110,000	36·6	30	
Gondola.	Wood.	60,000	26,800	47·0	703	...	...	30·9	66,000	40·6	31	(3)
—	Steel underframe.	100,000	46,700	46·7	891	...	...	31·8	110,000	42·5	32	
						Coke.						
Coke rack.	Wood.	60,000	30,800	51·3	2,042	61,260	50·3	66·5	66,000	46·9	33	
—	Steel.	100,000	44,400	44·4	3,458	103,740	42·8	70·0	110,000	40·5	34	
Coke.	—	100,000	52,000	52·0	3,406	102,180	50·9	66·3	110,000	47·2	35	
—	—	100,000	45,600	45·6	2,850	85,500	53·3	65·2	110,000	41·5	36	
Box.	Wood.	60,000	30,200	50·3	1,947	...	...	33·5	66,000	45·8	37	
—	—	80,000	35,000	43·7	2,032	...	...	30·4	88,000	39·8	38	
—	Steel underframe.	100,000	44,300	44·3	2,448	...	...	30·7	110,000	40·3	39	

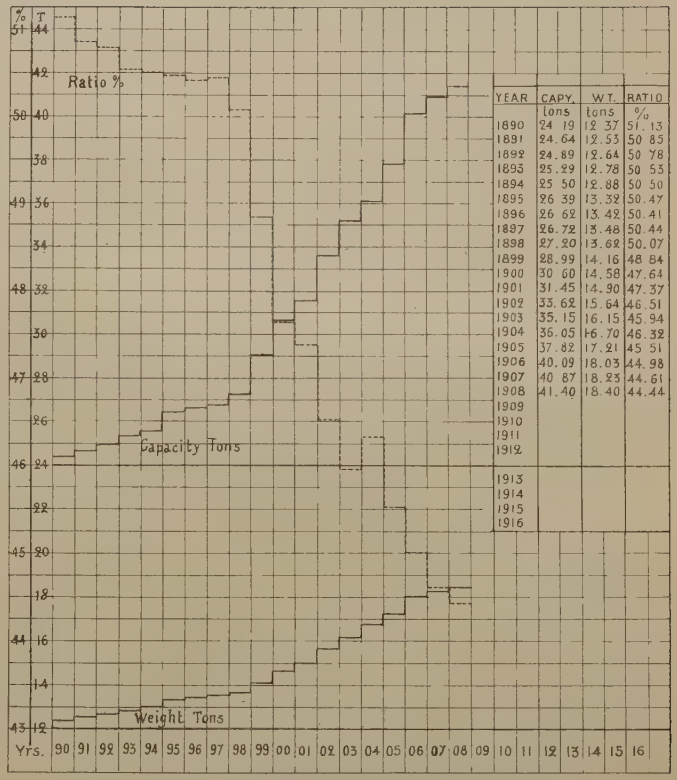
(1) Cars provided with steel wheels loaded to maximum shown. — (2) Cars have 44 inch sides. — (3) Cars have 30 inch sides.



Cars, freight, average, capacity and weight, 1890 = 100 per cent.

Fig. 40. — Cars, freight, equipement Pennsylvania Lines-West, average capacity and weight. Increase, per cent : 1890 = 100 per cent.

——— Average weight.
– – – – Average capacity.
..... Average lading (Loaded cars).
—·—·— Average lading (All cars.).



YEAR	CAPY. tons	WT. tons	RATIO %
1890	24 19	12 37	51.13
1891	24.64	12.53	50 85
1892	24.89	12.64	50 78
1893	25.29	12.78	50 53
1894	25 50	12.88	50 50
1895	26 39	13.32	50.47
1896	26 62	13.42	50.41
1897	26.72	13.48	50.44
1898	27.20	13.62	50.07
1899	28.99	14.16	48 84
1900	30 60	14.58	47.64
1901	31.45	14.90	47.37
1902	33.62	15.64	46.51
1903	35.15	16.15	45.94
1904	36.05	16.70	46.32
1905	37.82	17.21	45 51
1906	40.09	18.03	44.98
1907	40 87	18.23	44.61
1908	41.40	18.40	44.44
1909			
1910			
1911			
1912			
1913			
1914			
1915			
1916			

Cars, freight equipement, average capacity and weight.

Fig. 41. — Cars, freight, equipement Pennsylvania Lines-West, average capacity and weight.

67·5 per cent in the average paying load per car in the year 1907, when the maximum service was being rendered by the railways in America, over the average paying load per car in 1890.

While the average paying load per car increased 67·5 per cent, the average weight of the vehicles used in 1907 increased by but 47·5 per cent as compared with those used in 1890.

Figure 41 gives a statement and shows graphically the average capacity, average weight and the ratio of weight to capacity of the cars of the Pennsylvania Lines West of Pittsburgh for each year from 1890 to 1908, inclusive. The diminished percentage of the dead weight to the capacity is clearly illustrated.

At large terminals, yards and industries the space or track room occupied by cars containing a given quantity of material is of importance, and the cars of higher capacity reduce considerably the track room and yard space given up to take care of the traffic. Statement B gives the capacity in pounds and cubic feet per lineal foot of track occupied.

Statement B.

Figure.	Kind.	Material.	Capacity in pounds per lineal foot of track occupied.	Capacity in cubic feet per lineal foot of track occupied.	Pounds weight per cubic foot of capacity.
25	Hopper.	Wood.	1,983	372·9	23·6
26	Hopper.	Wood.	3,150	439·4	28·8
27	Hopper.	Steel.	2,920	559·0	20·4
33	Coke rack.	Wood.	1,782	603·6	15·1
34	Coke rack.	Steel.	2,381	823·3	12·8
35	Coke.	Steel.	2,277	775·6	15·3
36	Coke.	Steel.	2,273	647·8	16·0
28	Gondola.	Wood.	1,607	328·7	23·4
29	Gondola.	Wood.	2,143	333·2	26·5
30	Gondola.	Steel.	2,381	380·3	25·2
31	Gondola.	Wood.	1,607	188·3	38·1
32	Gondola.	Steel underframe.	2,222	198·0	52·4
37	Box.	Wood.	1,545	501·4	15·5
38	Box.	Wood.	2,060	523·3	17·2
39	Box.	Steel underframe.	2,469	604·5	17·3

This factor is particularly important in the mineral traffic, on account of limited car storage space usually available at mines, docks and furnaces.

Service comparisons. — Average train of locomotive loading. From tests it has been determined that the average resistance to traction of freight cars at slow speed on level track varies for cars of different weights and, while the results obtained in different tests show considerable variation, the writer will assume that the resistances given in the following tabulation are sufficiently accurate for these comparisons.

Statement C.

Resistance in pounds per ton for eight-wheel cars of various weights.

Slow speed.		Level track.	
Weight of car	10 tons.	Resistance per ton	14·9 pounds.
— —	20 —	— —	8·0 —
— —	30 —	— —	5·7 —
— —	40 —	— —	4·5 —
— —	50 —	— —	3·8 —
— —	60 —	— —	3·4 —
— —	70 —	— —	3·0 —

Figure 42 shows the above graphically.

The effect of this difference in resistance on the paying load per train is illustrated below by taking the data compiled for the diagram, figure 41 and showing the results obtained from trains made up of cars of the average weight and average lading shown for the years 1890, 1895, 1900, 1905 and 1907.

Statement D.

Average train lading. — Cars of various weights locomotive assumed 20,000 lb. drawbar pull at 15 miles per hour. — Level track.

Year.	Weight of car and lading, tons.	Resistance per car, pounds.	Number of cars per train.	Tons per train.	Tons per lading.	Ratio of paying load to total.	Construction.
1890	26·5	167·0	119	3,150	1,677	53·2	Wood.
1895	29·0	169·5	118	3,420	1,830	53·5	Wood.
1900	33·0	174·5	115	3,795	2,120	56·0	Wood and steel.
1905	39·0	180·0	111	4,340	2,425	56·0	Wood and steel.
1907	42·5	184·0	109	4,620	2,650	57·2	Wood and steel.

That is, with the larger capacity cars in use in 1907, a given locomotive can haul about 60 per cent more paying load than it could have hauled in the cars of lower capacity in use in 1890.

The above statement refers to the average weight and the average lading of cars

and, of course, covers all kinds of commodities carried, many of which tax the cubic capacity rather than the weight carrying capacity. It is therefore considered desirable to give a further comparison of the effect of the cars of wooden and steel construction on the average train and locomotive loading by giving examples of trains made up of selected cars. These trains represent the results obtained in certain districts under heavy traffic conditions.

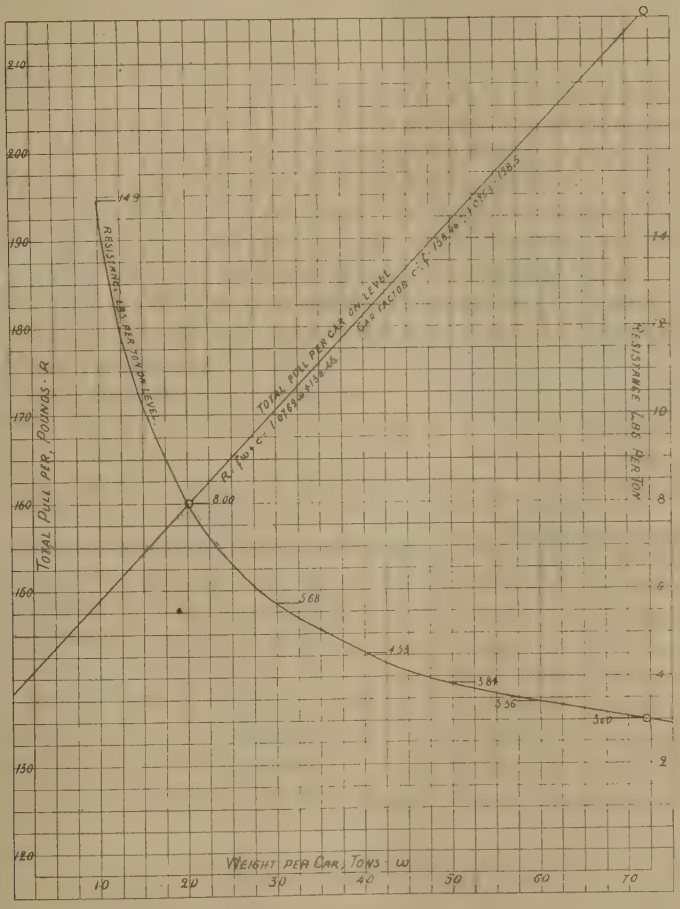


Fig. 42. — Resistance of freight cars of various weights.

Note. — 8 lb. per ton, level tangent resistance of a 20 ton car, was average of 3 tests on the Pgh. Div. New Portage R. R. 1907.
3 lb. per ton, for a 72 ton car was average of 15 tests on Phila. Div., Low Grade Freight Line, 1907.

Selecting for comparison trains made up as follows :

Comparison A.

1° Hopper car, wooden construction, figure 25, loaded with coal;
2° — — — — 26, — —
3° — steel — — 27, — —

Comparison B.

1° Hopper car, wooden construction, figure 25, loaded with ore;
2° — steel — — 27, — —
3° — — — — 27 (steel wheels), loaded with ore.

Comparison C.

1° Coke rack car, wooden construction, figure 33, loaded with coke;
2° — — steel construction, figure 34, loaded with coke;
3° — steel construction, figure 35, loaded with coke;
4° — — — — 36, — —

The coke cars illustrated in figures 33 and 34 have small doors in the floor; while those shown in figures 35 and 36 are designed to be self-clearing, the necessary slope sheets, doors and door operating mechanism add to the weight. Data is not available to give comparison of a self-clearing coke car of wooden construction with these. Statement E gives data regarding the average train lading for the selected types of calculated by the same method as used in obtaining the information given in statement D.

Statement E.

Average train lading. — Cars of various weights locomotive assumed 20,000 lb. drawbar pull at 15 miles per hour. — Level track.

CARS FIGURE.	Weight of car and lading, in tons.	Resistance per car, in pounds.	Number of cars per train.	Tons per train.	Tons per lading.	Ratio of paying load to total.	Construction.
Comparison A. — LOADING OF COAL.							
25	42·5	184·0	109	4,620	3,200	69·0	Wood.
26	56·0	199·0	100	5,600	3,627	64·7	Wood.
27	60·0	210·0	95	6,550	4,700	71·7	Steel.
Comparison B. — LOADING OF ORE.							
25	46·5	188·0	106	4,925	3,500	71·0	Wood.
27	74·5	219·0	91	6,800	5,000	73·5	Steel.
27	80·0	225·0	89	7,100	5,370	76·0	Steel.
Comparison C. — LOADING OF COKE.							
33	46·0	188·5	105	4,825	3,240	67·0	Wood.
34	74·0	218·5	91	6,750	4,725	70·0	Steel.
35	77·0	221·0	90	6,900	4,600	67·0	Steel.
36	65·5	209·5	96	6,300	4,100	65·0	Steel.

To show that advantage is taken in practice of the increased train loading

obtainable with cars of steel construction a sheet from locomotive rating schedule of the Pennsylvania Lines West of Pittsburgh is shown in statement F.

Statement F.

Pennsylvania Lines West of Pittsburgh

NORTH-WEST SYSTEM.

NOTICE.

The ratings given on the following sheets include the resistance.

In computing the tonnage of a train the resistance figure given should be added to the total weight of each car (whether loaded or empty), in the train.

Where different ratings are given for different types of locomotives of the same class, care must be taken to use the proper rating.

The "A" rating should be used always unless otherwise ordered.

Train Masters may authorize the departure from the "A" rating to meet sudden emergencies, such as a fall in temperature, heavy snow, heavy winds, etc., but these changes must not be kept in effect longer than 24 hours without formal authority from the Superintendent.

Superintendent.

APPROVED:

A. M. SCHOYER,

General Superintendent.

HAULING CAPACITY OF LOCOMOTIVES
SLOW FREIGHT.
P. Y. & A. R. R.

ENGINES.	Harbor-Austinburg.				Austinburg-Conway.			
CLASS.	A	B	C	D	A	B	C	D
G 31, G 3, 4c H 2a	675	625	575	475	1,900	1,775	1,600	1,325
F 31, 3c H 2 and H 2a	725	675	600	500	2,050	1,900	1,725	1,425
G 3a, G 32, 2c H 2 and H 2a	750	700	625	525	2,125	1,975	1,775	1,475
H 30, G 33, 1c H 2 and H 2a	800	750	675	550	2,275	2,125	1,900	1,600
H 3a, H 3b	850	800	725	600	2,425	2,250	2,025	1,700
H 3c, F 1, G 4	1,000	925	850	700	2,825	2,625	2,375	1,975
H 4	1,250	1,150	1,050	875	3,500	3,250	2,950	2,450
H 6a	1,375	1,275	1,150	950	3,900	3,625	3,275	2,725
H 8a, H 28	1,475	1,375	1,225	1,025	4,175	3,875	3,500	2,925
G 4a	1,125	1,050	950	775	3,175	2,950	2,675	2,225
D 8a, D 9a, D 10a,	525	500	450	375	1,475	1,375	1,250	1,025
D 9, D 10, G 30	600	550	500	425	1,700	1,575	1,425	1,200
D 29	400	375	325	275	1,125	1,050	950	775
E 2, E 2a, E 2b, E 2c E 28, E 29	825	775	700	575	2,350	2,200	1,975	1,650
J 28	950	900	800	650	2,750	2,550	2,275	1,925
K 28	1,150	1,075	975	775	3,250	3,000	2,700	2,275
	Resistance, 5 Tons per Car				Resistance, 13 Tons per Car			
	East Bound.				East Bound.			

ERIE & ASHTABULA DIVISION.

It will be noted that with the method of locomotive rating a fixed allowance in tons is added to the weight of each car to compensate for decreased weights of train it is possible to haul as the number of vehicles containing a given weight is increased.

Methods of rating locomotives which make allowance for the difference in weights of cars, and consequently the number of cars in a train, similar in theory to the above, are used by many of the railroads in America, although they differ in detail as to application and form in which they are promulgated.

To illustrate the advantage obtained by the use of cars of large capacity, the following example is given :

For movement between Austinburg and Conway two (2) class H6a locomotives and a sufficient number of the hopper cars of wooden construction illustrated by figure 25 and hopper cars of steel construction as shown by figure 27, loaded with ore to make two trains are available. One train is to be made up of cars of wooden construction and one of cars of steel construction. From statement F it will be noted that the hauling capacity of the class H6a locomotive is 3,900 adjusted tons between the points named and that the car allowance, or resistance, as it is called for convenience is 13 tons per car, therefore, the two trains would be made as shown in statement G.

Statement G.

Comparison of trains.

TYPE OF CARS.	Number of cars per train.	Weight of train cars and lading, in tons.	Weight of train lading, in tons.	Ratio of paying load to total.	Construction.
Figures 25.	66	3,030	2,140	70·5	Wood.
— 27.	45	3,350	2,480	74·0	Steel.
Difference . . .	−21	+320	+340	+3·5	...
Per cent . . .	−32	+ 10·5	+ 16·0	...	...

That is, a given locomotive would haul in the cars of steel construction 16 per cent more paying load than it would in the cars of wooden construction, and to move the traffic there would be required twenty-one less cars, of which the first cost, interest and maintenance charges must be considered.

At many industries, for unloading ore from cars, and at the lake ports and seaboard where coal is tranferred from cars to boats, machines have been provided by which the complete car is raised in a cradle and the cradle and car overturned to discharge the entire contents of the car; cars are handled through these machines at a rate of thirty per hour.

In addition to better withstanding the wear and tear incident to the operation

better than the wooden cars, the cars of steel construction, on account of their greater carrying capacity, permit the unloading of 1,500 tons of coal per hour, instead of 900 tons per hour as would be the case with cars of wooden construction?

This increase in the output of the unloading machines is important as it not only saves the investment for additional machines and their upkeep and operating expense, but reduces the yard and track room required therewith and the amount of property and number of docks required to handle a given amount of traffic, as well as minimizing the delay to boats receiving the cargo.

It might seem that much of the above was not pertinent to a report on the use of steel in locomotive and car construction, but your reporter deems it essential to any consideration of the subject.

While it is true cars of wooden construction of large capacity would permit of obtaining results approaching those obtained with cars of steel construction, it is a fact that wooden cars having capacities equal to the steel cars would weigh more, have less strength and cost more to maintain, therefore, the use of steel is necessary to obtain the results as given.

Truck side frames. — In the construction of trucks for freight cars, it has been the practice by practically all of the railways in America to use what is known as the arch bar truck, similar to that illustrated by figure 43. In this construction, the arch bars and tie bars are usually made of wrought iron, although in some cases mild steel has been used.

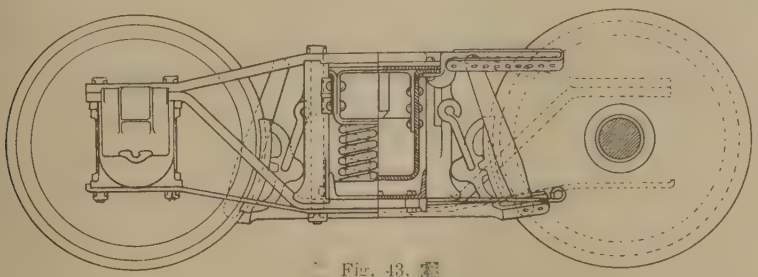


Fig. 43.

Since 1905, a number of railways have substituted a steel casting side frame for the top and bottom arch bars, so as to reduce the number of parts and the number of bolts, nuts, etc., to be maintained. Figures 44 and 45 illustrate the general type of side frames of steel castings which have been extensively used, and, at the present time there may be obtained from several manufacturers side frames of this type, although differing in detail from those illustrated.

Several manufacturers have designed and manufactured side frames of steel

castings which include in one piece the entire journal box or the upper part of it.

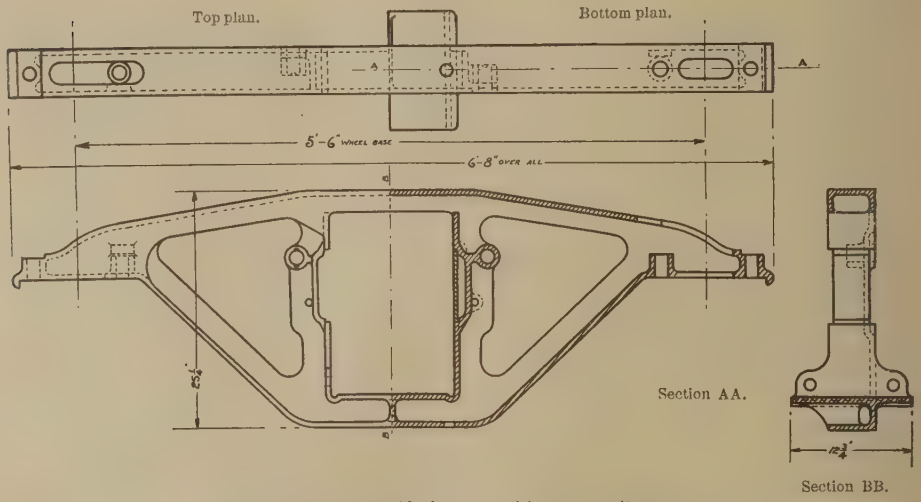


Fig. 44. — Truck side frame. — 50 ton capacity cars.

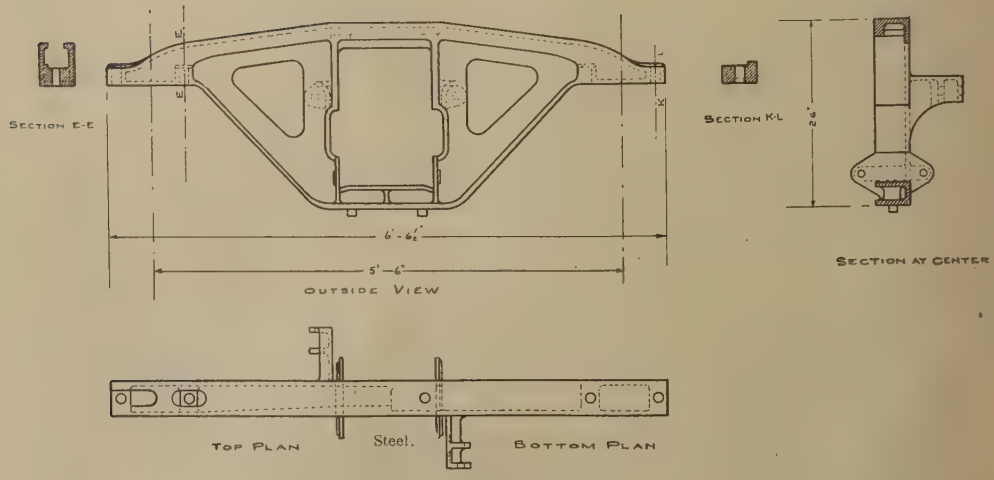


Fig. 45. — Truck side frame.

Figure 46 shows a side frame which includes the entire journal box (except the lids), which can be compared with arch bar construction in general use figure 43. These figures indicate the reduction in the number of parts which may be made and give an excellent idea of the tendency to simplification in design.

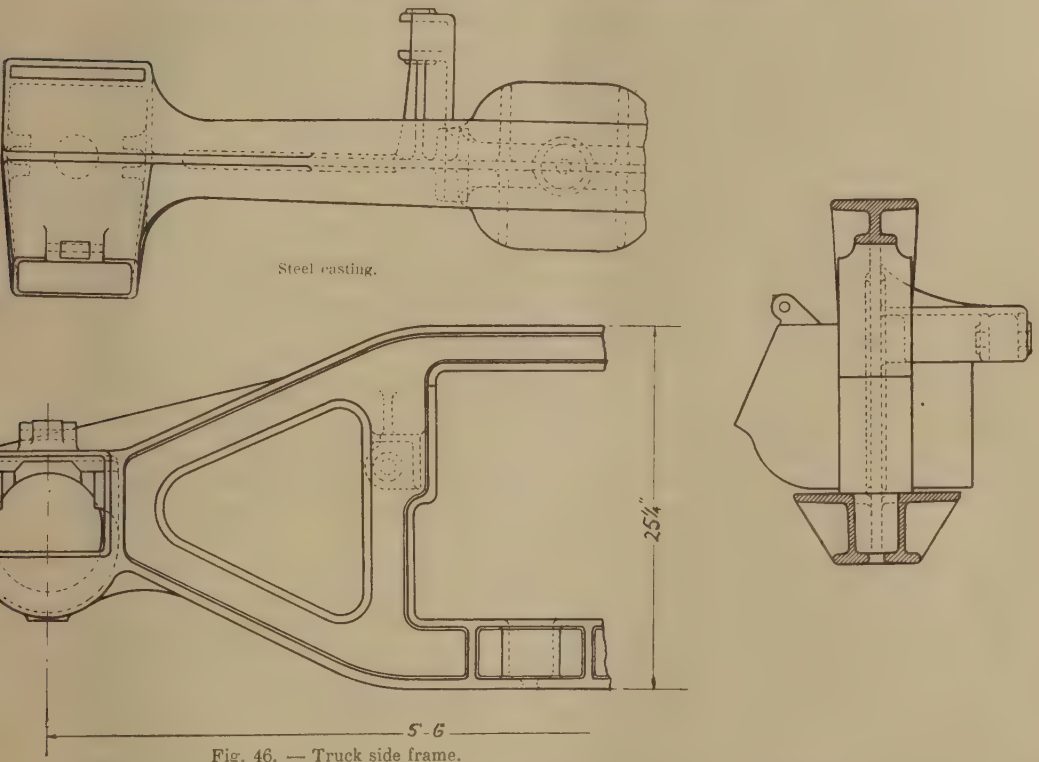


Fig. 46. — Truck side frame.

While truck frames of all of the types illustrated have been extensively used, they have not been in service a sufficient length of time to give any data as to the ultimate economy that may be obtained.

The large number used and the adoption of the device by many railroads, in the opinion of the writer, justifies its presentation to the Congress as an example of the use of steel in car construction.

The initial cost of the steel casting construction compares favorably what that of trucks of the arch bar type.

Journal boxes. — For many years the journal boxes for cars built for the railways

in America have been made of either cast iron or malleable iron castings. Recently journal boxes made of steel castings have been produced at a cost which compares favorably with the cost of similar boxes made of malleable iron castings and undoubtedly the increased strength of the metal will lead to their extensive use.

A journal box made up of a steel casting top with pressed steel sides is also available and has been used on several thousand cars built for various railroads.

The comparatively small weight as well as the increased strength make the steel journal boxes attractive to car designers and serve to illustrate to the Congress the extent that steel is being considered in American car design.

Wheels. — Wheels of cast iron which have the tread and wearing portion of the flange cast against chills have been almost universally used for the freight carrying cars in service on the railways of America. Although the service rendered by the wheels made of this comparatively inexpensive material has been remarkable, the increase in the weight to be carried per wheel, the difficulty experienced in maintaining them under the heavier cars and the expense, lead to the consideration of material which would permit the manufacture of a wheel of greater strength and durability.

While many forms of built-up wheels, having cast iron, wrought iron or steel casting centers, with steel tires, were available, the cost was so high that the use of such wheels for freight carrying cars was prohibited. The steel casting seemed to offer a solution of the difficulty and some wheels made by pouring the molten steel into suitable moulds, were manufactured; no further work than truing the tread and flange being required. Wheels made in this manner have not as yet been extensively used, as many of those produced were defective or failed to render the service which was to be expected from them in view of their cost.

Wheels made of steel castings having a higher percentage of manganese in the tread and flange than in the remainder of the wheel have been produced by double pouring or similar methods, are now undergoing service trials, but have not been in service a sufficient length of time to permit the presentation of accurate data.

The manufacture of the solid forged and rolled steel wheels on a commercial basis was established in May, 1903, by Mr. Chas. T. Schoen, the pioneer builder of high capacity cars of steel construction. In the earlier experiments made by Mr. Schoen, a steel casting of a form approaching closely that desired in the finished product was made and after reheating, was rolled by a specially designed rolling mill to the finished size. Wheels made in this manner did not prove satisfactory and this process was therefore abandoned and the method now followed adopted. Although the process of manufacture of the Schoen wheel has been described fully in the technical papers, your reporter will refer to it briefly so that comparison may be made with the other methods of manufacturing solid forged and rolled wheels.

For the Schoen solid steel wheel open hearth steel of the composition given below is used :

Carbon.	0·65 to 0·85 per cent.
Manganese	0·60 to 0·85 —
Silicon	0·08 to 0·25 —
Phosphorus, not to exceed	0·05 per cent.
Sulphur, not to exceed	0·05 —

The ingot is rolled into a slab of proper thickness and sheared to a square of the dimensions necessary for the required diameter of the wheel, about 25 per cent of the ingot being discarded te insure sound metal.

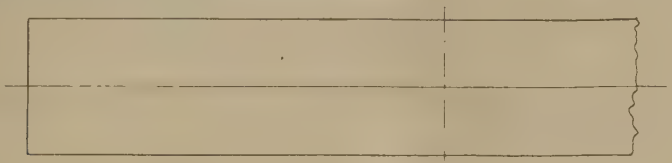


Fig. 47. — Section of rolled steel-slab.

Figure 47 shows size and thickness of the slab.

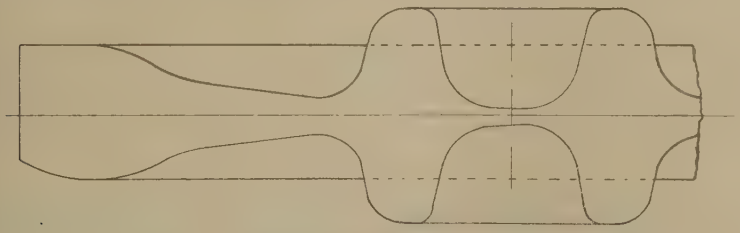


Fig. 48. — Section of blank at first forging and shearing.

Figure 48 shows the partially formed wheel after the first forging operation, the slab having been heated and forged under 7,000 tons pressure and sheared to circular form.

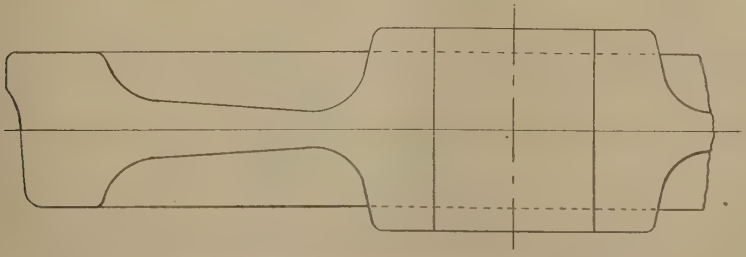


Fig. 49. — Section of blank after second forging and punching hole in hub.

Figure 49. The wheel has been reheated and forged under 5,000 tons pressure and the rim subjected to an extra forging operation before withdrawing from the press.

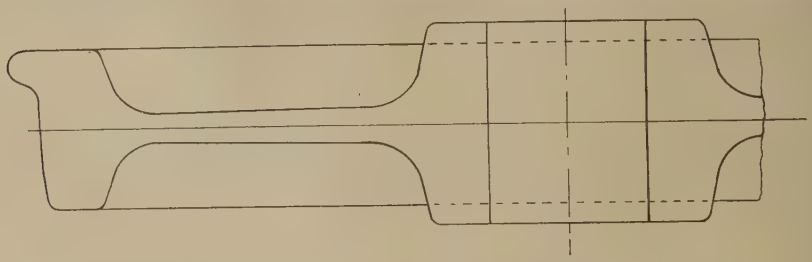


Fig. 50. — Section of wheel after rolling web and rim.

Figure 50. After re-heating for a short time the wheel has been rolled in a specially constructed machine.

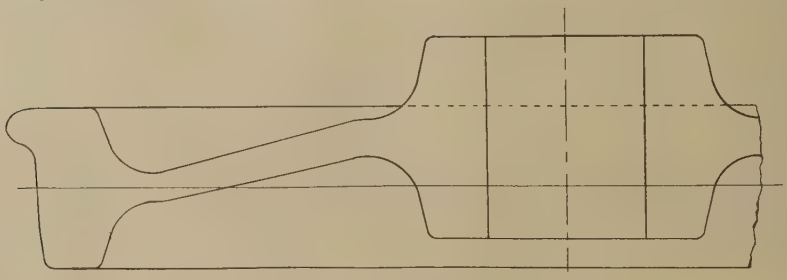


Fig. 51. — Section of wheel dishing and perfecting.

Figure 51. The wheel has been dished and made truly round under 1,200 tons pressure and is ready for service as ordinarily used for freight carrying cars. Wheels for passenger cars have the treads turned when desired.

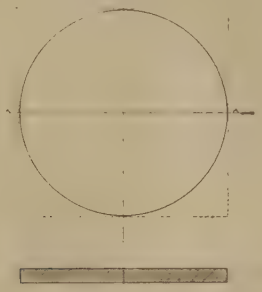
The forging and rolling process admits of working very close to the dimensions and without machining the wheels are made to the following tolerances :

Height of flange	Variation not greater than $^1/_{16}$ inch.
Width —	— — — $^1/_{16}$ —
Throat radius	— — — $^1/_{16}$ —
Eccentricity of bore . . .	The eccentricity between the tread at its center line and the rough bore not to exceed $^3/_{64}$ inch.
Rotundity	When gauged with ring gauge the opening between gauge and tread not to exceed $^1/_{16}$ inch at any point.
Plane	When wheels are gauged with a four-point or ring gauge placed concentric with and perpendicular to the axis of the wheel, all points on the back of the rim to be equidistant within a variation of $^1/_8$ inch from the plane of the gauge when so placed.

During 1907 the Forged Steel Wheel Company commenced to manufacture steel wheels by the process developed by Mr. J. M. Hansen. In this process forging by hydraulic pressure only is involved, the forged wheels not being rolled as in the Schoen process just described.

The steel used is open hearth steel similar in composition to that mentioned above, particular care being taken to select metal having a very small amount of phosphorus or sulphur.

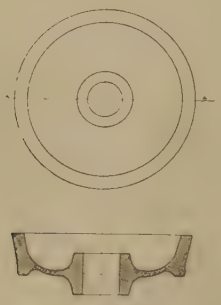
The ingot is rolled into a slab of the required width and thickness for a wheel of the required dimensions and the slab out into squares. After being heated in a continuous furnace having a temperature range from 600° C. in the end where the steel is entered to 1,250° C. in the end where the material is withdrawn, the square blank is cut to circular shape as shown in figure 52.



Section A-A.

Fig. 52.

and without further heating is forged under the hydraulic forging press into the shape shown by figure 53, this operation completing the hub and plate.



Section A-A.

Fig. 53.

When removed from the dies the blank has a temperature of about 700° C. and it is immediately placed in a reheating furnace and heated to a temperature of about 1,200° C.

With this heat the second and third forging operations are completed producing the shapes shown by figures 54 and 55 respectively.

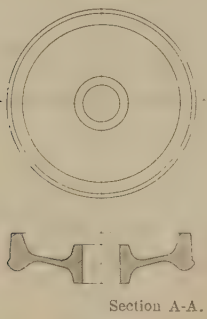


Fig. 54.

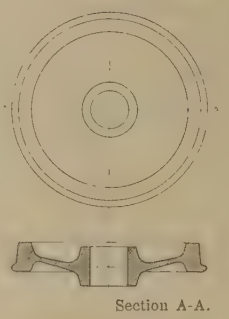


Fig. 55.

When the wheel is removed from the dies it has a temperature of from 750 to 800° C. and is placed in annealing pits and permitted to cool slowly. In about 48 hours, it is cold enough to handle, when it is taken to the finishing mills where the hub is rough bored and faced and the tread and flange turned to the contour desired.

Solid forged and rolled steel wheels are also manufactured by the Midvale and Standard Steel Companies, the process being similar to that used in making tires of the smaller sizes; that is, an ingot is cut transversly into discs and these are forged and rolled to produce the desired shape.

All of the manufacturers use steel of about the same composition and work to the same tolerances as to dimensions.

That the forged steel wheel is favorably regarded by the railways is indicated by the fact that since the Schoen plant started in 1903, 203,000 wheels for railway locomotives and cars and 56,000 wheels for street railway cars have been manufactured in their plant; for use on railway equipment these wheels were distributed as follows :

Locomotive trucks	6,000
Freight cars and tender trucks	165,000
Passenger cars	32,000
Total wheels. . .	203,000

A small number of these solid wheels have been made of special steels, principally vanadium steel, and now undergoing service trials.

Solid forged steel wheels are produced for about one-half the cost of a steel tired wheel of the same diameter and general dimensions and the net cost is about three times the net cost of the chilled cast iron wheels. Net cost is the difference between the cost of the wheel when new and the amount obtained for the worn out wheel when removed from service.

At the present relatives prices of the solid steel wheels and the cast iron wheels, with proper allowance for salvage in each case, the indication from service tests is that the cost per mile for the steel wheel will compare favorably with the cost of the cast iron wheel per mile, allowance being made for interest on the increased investment involved in the use of the steel wheel.

From the evidence so far obtained, it will be possible to obtain solid steel wheels of much greater strength than the wheels made of cast iron for about the same service cost, and improvements may be expected to make the comparison still more favorable to the steel wheel.

From tests made by Mr. Geo L. Fowler it was found that the flange of a cast iron wheel could be broken off by an applied pressure of from 60,000 to 110,000 pounds, while to break off the flange of a steel wheel required the application of 526,612 pounds pressure.

In service some trouble has been experienced with the solid wheels on account of lamination of the metal in the treads similar to the lamination which sometimes occurs in steel tires. Improvement in shop methods and larger experience in manufacturing, however, have reduced the percentage of wheels showing evidence of lamination and further experience will, no doubt, practically eliminate the defect.

The standard axle of the Master Car Builder's Association for cars of 100,000 pounds capacity is of such dimensions and material that when worn to the limits of wear prescribed by the Association it will have ample factor of safety if the total weight of the car and lading carried by four axles does not exceed 161,000 pounds. Although improvements have been made in the manufacture of the cast iron wheels for cars of 100,000 pounds capacity, it has been the general pratice to limit the weights carried on eight wheels to about 150,000 pounds. In some cases where steel wheels have been applied to cars, the marked or nominal capacity has been increased to 110,000 pounds, this, with 10 per cent of excess lading permitted, making the cars available to carry 121,000 pounds of lading when the nature of the lading is such that the cubical contents of the car will admit holding this amount.

A number of the cars illustrated by figure 27 have been provided with steel wheels and when loaded with iron or other heavy material are loaded to 121,000 pounds; this, with a car weight of 39,000 pounds, makes a total load of 160,000 pounds, or within the limit permitted on the standard axle.

With steel wheels, the car illustrated by figure 36 would be capable of carrying 115,000 pounds of coal without exceeding the axle limits.

It is desirable to increase the nominal capacity of cars having the steel wheels from 100,000 pounds to 110,000 pounds for two reasons :

1° The increase in the paying load at least makes up for the higher charge for interest necessary on account of the larger investment;

2° It tends to prevent the use of cast iron wheels under such cars as the steel wheels are a necessary part of the higher capacity cars.

CONCLUSIONS.

From examination of the designs and construction of the freight carrying cars recently built and building for the railways in America, your reporter draws the following conclusions :

1° Cars of steel construction or with steel underframes will be substituted for cars of wooden construction;

2° Steel will be used more extensively for that portion of the car now made of wood; that is, the side framing, end framing and roof carlines and similar parts will be of steel;

3° Steel castings and pressed steel and structural steel shapes will be substituted for parts now made of cast or wrought iron;

4° The manufacture of steel wheels has made sufficient progress to permit of their consideration for the high capacity cars;

5° The use of steel in freight car construction has permitted the development of cars of maximum capacity and minimum weight consistent with strength;

6° Cars of the greater capacity permissable with the steel construction facilitate the movement of traffic in many ways and assist in obtaining economical maintenance and operation.

Passenger cars.

General. — The effect of service in heavy and high speed trains, cost of maintenance and damage to equipment, and in some cases injury to passengers in accidents, caused a demand for cars of stronger construction than that of the cars ordinarily used. This demand was partially met in cars constructed of wood by increasing the strength of the parts affected by the pulling and buffing strains, the use of metal platform construction and the application of vestibules and buffers.

In several accidents cars were destroyed by fire, and in some cases the occupants were more or less seriously burned; this naturally suggested the use of less inflammable material in car construction.

As the use of electric motor for traction purposes was increasing rapidly, Mr. George Westinghouse, in January 1902, called attention to the dangers of fire incident to the use of electric power and suggested the use of non-inflammable materials in car construction, especially for elevated railway and subway service, where it would be difficult for the passengers to leave the cars quickly. This warning caused considerable discussion as to the necessity for any change in material used in car construction, but the number of cases of surface, elevated and subway cars operated by electric power, as well as the number of cars of steam railway trains, which have been destroyed by fire in accidents, clearly indicated the necessity for such construction as would reduce the liability of fire to a minimum.

The successful use of metal in the construction of freight cars led to the consideration of its use for passenger cars; the earlier designs contemplating the use of metal underframing with wooden superstructure; this construction, while improving the situation insofar as strength is concerned, did not sufficiently reduce the danger from fire. Therefore the later designs have been based on the use of metal, eliminating the inflammable material as much as practicable.

Number of all-steel and steel underframe cars. — Several of the railways in America have in service, passenger train cars, and others are building or have under consideration at the present time, the design of passenger train cars of all-steel or steel underframe construction.

Information obtained from the various car builders shows they have built to date for steam railway service, the following number of passenger train cars in which metal is extensively used :.

Steel underframe cars	400
All-steel cars	900

The Pennsylvania Railroad System have had built, or have under construction, passenger train cars of all-steel construction as follows :

Passenger cars	392
Combined passenger and baggage cars	75
Dining cars	44
Postal or mail cars	82
Baggage and mail storage cars	93
Total	686

The above is given only to show that the use of steel is extended to all types of passenger train cars.

The Pullman Company, which operates the majority of the sleeping cars in ser-

vice on the railways in America, has under construction, a large number of sleeping cars of all-steel construction.

Illustrations of type and design. — In changing from wood to metal in car construction, full advantage of the possibilities of the distribution of the metal should be taken, rather than simply substituting the metal for wood, in the same general form of construction of that of the wooden car.

In America, in wooden car construction, it has been the practice in designing, to so distribute the material as to carry the weight of the superstructure and load on trusses placed in the sides of the car, reinforced by truss rods; it being impracticable to make the center sills sufficiently deep to carry the load over the long span from center to center of trucks.

In metal car construction, however, it is possible to either concentrate the strength in the metal center sill or to substitute metal girders for the trussed sides used in wooden car construction.

The designs prepared to the present time may be divided into three classes, *viz.* :

1° That in which the load due to the weight of the car body and lading is carried by the center girder which at the same time takes care of the pulling and buffing strains;

2° That in which the load due to weight of the car body and lading is carried by the side girders; an additional girder being provided at the center of the car for the pulling and buffing strains;

3° That in which the center and side sills with truss rods used in the wooden car construction is reproduced in metal.

While the majority of the cars built have been of the first class described, several of the later designs are of the second class described. Very few cars of the design covered by the third class have been built, and it does not seem likely that this type will be extensively used, as it does not permit of the best utilization of the possibilities in metal construction.

From a study of these designs it is found :

A. — For stresses other than pulling and buffing, cars of equal strength will be practically the same weight and cost for structure;

B. — Where pulling and buffing strains do not exceed about 100,000 pounds the weight and cost of the structure will still be practically the same;

C. — To resist pulling and buffing strains exceeding 100,000 pounds the weight of the car in which the sides carry the load will be increased, while the weight of the car of the first type would not be increased for strains within a limit of 400,000 pounds;

D. — Cars of the third type mentioned to have equal strength of the other types will weigh more.

Figure 56 illustrates the usual design of cars of wooden construction; cars of

this type having been built of a length of 70 feet between end sills, and with some additional truss rods and bracing have been made 75 feet long between end sills.

Figure 57 illustrates an all-steel car, 70 feet long between end sills and gives opportunity to compare the exterior appearance with car of wooden construction shown in figure 56.

Figure 58 shows the construction of the underframe and figure 59 the framing of the superstructure of the car shown in figure 57.

In this design the weight of the superstructure and load is carried by the center girder; this girder being of ample strength to withstand the assumed pulling and buffing strains.

In the design of the car illustrated in figures 56 to 58, the following data was used and assumptions made :

It having been the practice to assume for freight cars that the car must be capable of withstanding shocks of 300,000 pounds compression, whenever the car is shifted, and that such shocks very often are equivalent to 500,000 pounds, such cars were given a center sill construction capable of resisting such shocks without exceeding the elastic limit of the metal. Experience with freight cars in the past five (5) years indicates that this basis is none too high. From tests made by allowing a dynamometer car weighing 51,000 pounds to run down a grade at seven (7) miles per hour and collide with a train of loaded cars having the brakes set, a shock of 607,000 pounds (the capacity of the dynamometer) was recorded. A loaded steel freight car and the dynamometer car, weight 181,400 pounds, striking the train referred to above, at three and nine-tenths (3·9) miles per hour, caused a shock of 400,000 pounds. As cars in steam railway service come together and are coupled at speeds equal to or in excess of those mentioned, it could not be considered safe to assume shocks less than 300,000 or 400,000 pounds. In collisions between passenger and freight cars the passenger cars should not be seriously damaged, which would require the passenger car center sill construction to be at least as strong as the same parts of the freight car.

For passenger cars a higher factor of safety is desirable, therefore, the design of the center sill construction of the car illustrated is based on end shocks equivalent to 400,000 pounds compression, under which the combined stresses should be about 12,500 pounds per square inch and in no case exceed 15,000 pounds per square inch for cars used in heavy trains in through service, and not more than 20,000 pounds per square inch for cars used exclusively in suburban service.

The stresses in the framing throughout under static load do not exceed the usual practice of 12,500 pounds per square inch and none of the superstructure above the belt rail has been included in determining these stresses.

In carrying out this design it will be noted that structural and pressed or formed steel shapes have been used, and but a comparatively small number of castings have been used in parts subject to heavy strain.

Figure 60 illustrates the construction of the underframe for all-steel cars used by

the Pullman Company for sleeping and parlor cars. This design also includes the heavy center girder, but that portion of the frame immediately over the trucks and extending outward to and including the platform structure are large steel castings which are riveted to the wrought steel parts.

That type of car in which the sides form a girder to carry the weight of the superstructure and lading is illustrated in figures 64 and 65; the former showing the construction of the underframe and the latter the side framing.

Another design somewhat similar to that given above but embodying truss rods is illustrated in figure 61, showing the underframe, figure 62 the side framing and figure 63 the end framing.

Steel Passenger Car Design is the subject of an article in great detail by Mr. Charles E. Barba and Mr. Marvin Singer, published in the *American Engineer and Railroad Journal* of December, 1907, January, March, April, June and November, 1908. This article will, no doubt, be of interest in connection with this report.

Cars of the various types of design have as yet not been in service a sufficient length of time to obtain accurate data as to the comparative value of the designs.

In the construction of the cars it has been the desire to obtain in addition to the strength, cars containing the minimum amount of inflammable material. In the construction of the car illustrated by figure 57 but about 400 pounds of wood is embodied, wood being used only at points where the passenger's body is likely to come in contact with the material; such as window sash, window sills, seat arm rests, etc. There is also about 700 pounds of the so-called fire proofed pressed pulp or fibre boards used for the ceiling or headlining, and in some cars aluminium sheet has been used for the ceiling.

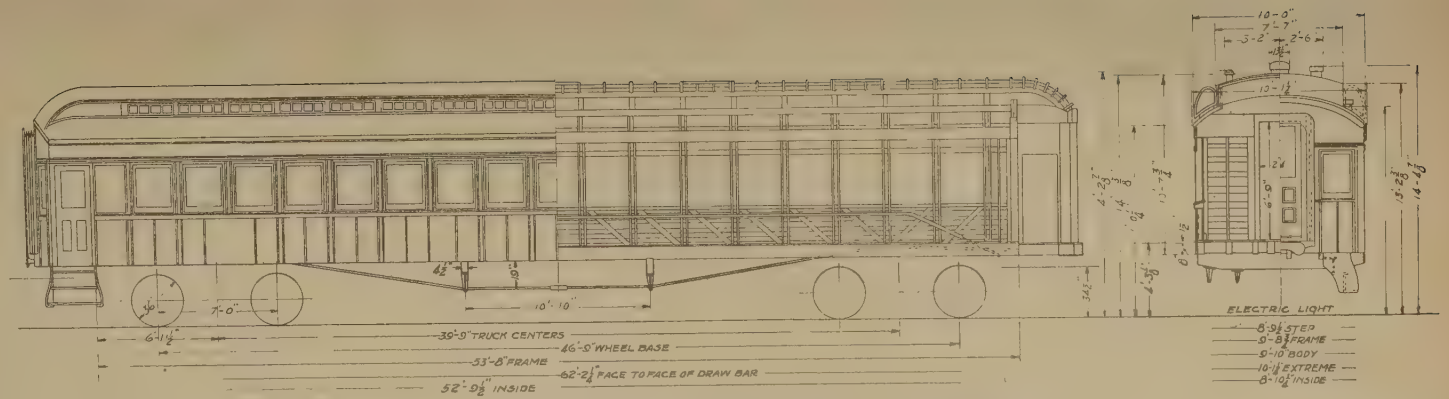
The interior lining, bulkheads, partitions, seat frames and similar appliances are all made of metal. The inflammable material is therefore confined to the fabrics used for the seat coverings and draperies, when the latter are used.

The figure 67 shows a car of the construction illustrated in figures 57, 58 and 59, arranged as a passenger carrying car of the usual type use on American railways, and figure 68 shows a car of the same construction, having a portion of it arranged to carry passengers and the remainder for baggage. A baggage car of the same general construction and frame design as that shown in figure 58 is illustrated by figure 69.

A copy of the specifications covering the details of construction of the cars referred to above, is appended to this report.

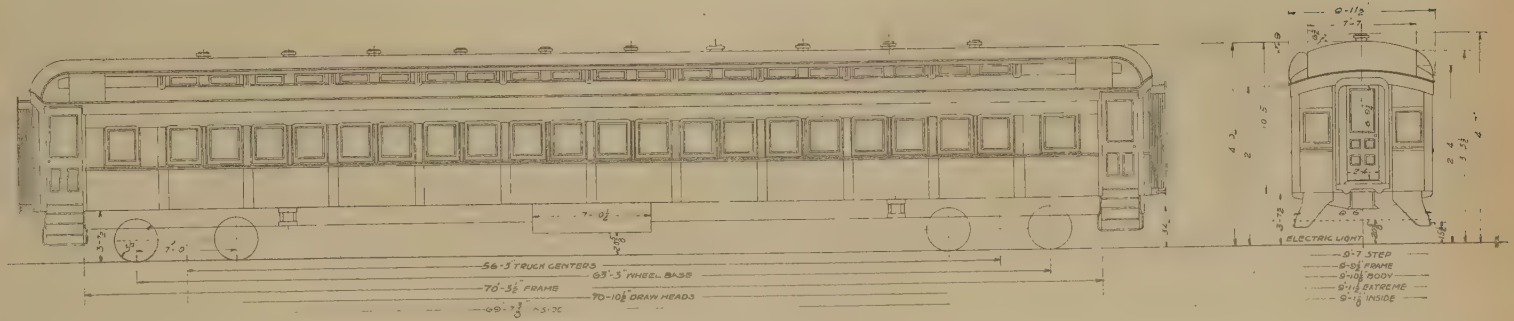
A car having the underframe and the sides up to belt rail (immediately below the windows) of steel construction, with the remainder of the superstructure of wooden construction is shown in figure 70.

Quality of steel. — For the construction of steel passenger cars open hearth steel of low carbon containing about 0·06 per cent of phosphorus is used. It has been found necessary in making specifications for the steel to permit the use of several grades for different parts of the car.



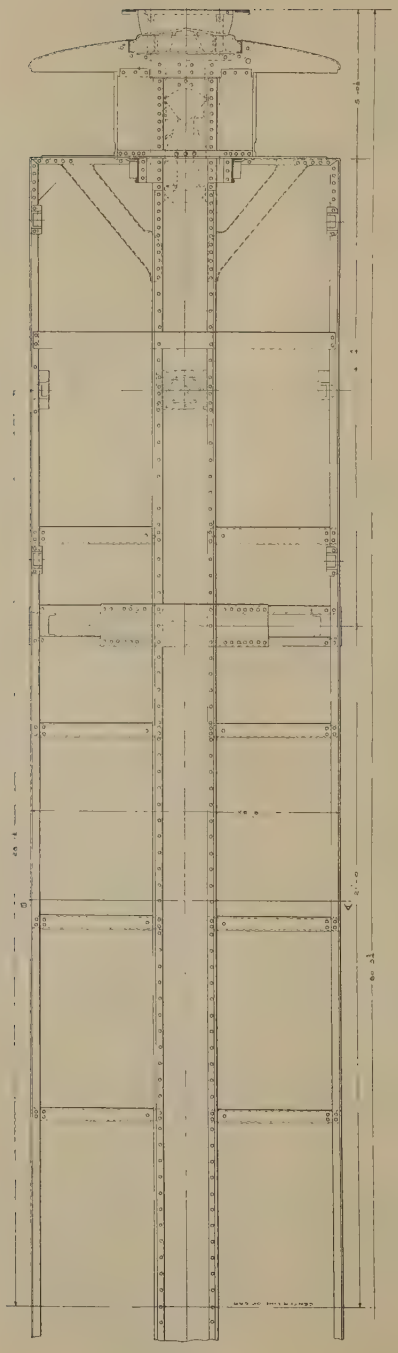
Total weight of empty car. — 92,000 lb. Weight of one truck : 16,000 lb.

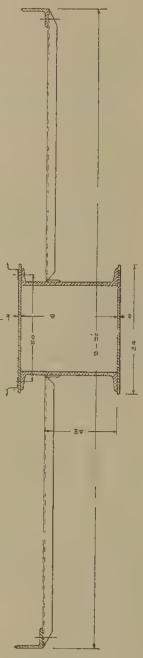
Fig. 56.



Total weight of empty car. — 114,000 lb. Weight of one truck : 13,000 lb.

Fig. 57.





Section A-B.

Fig. 58.

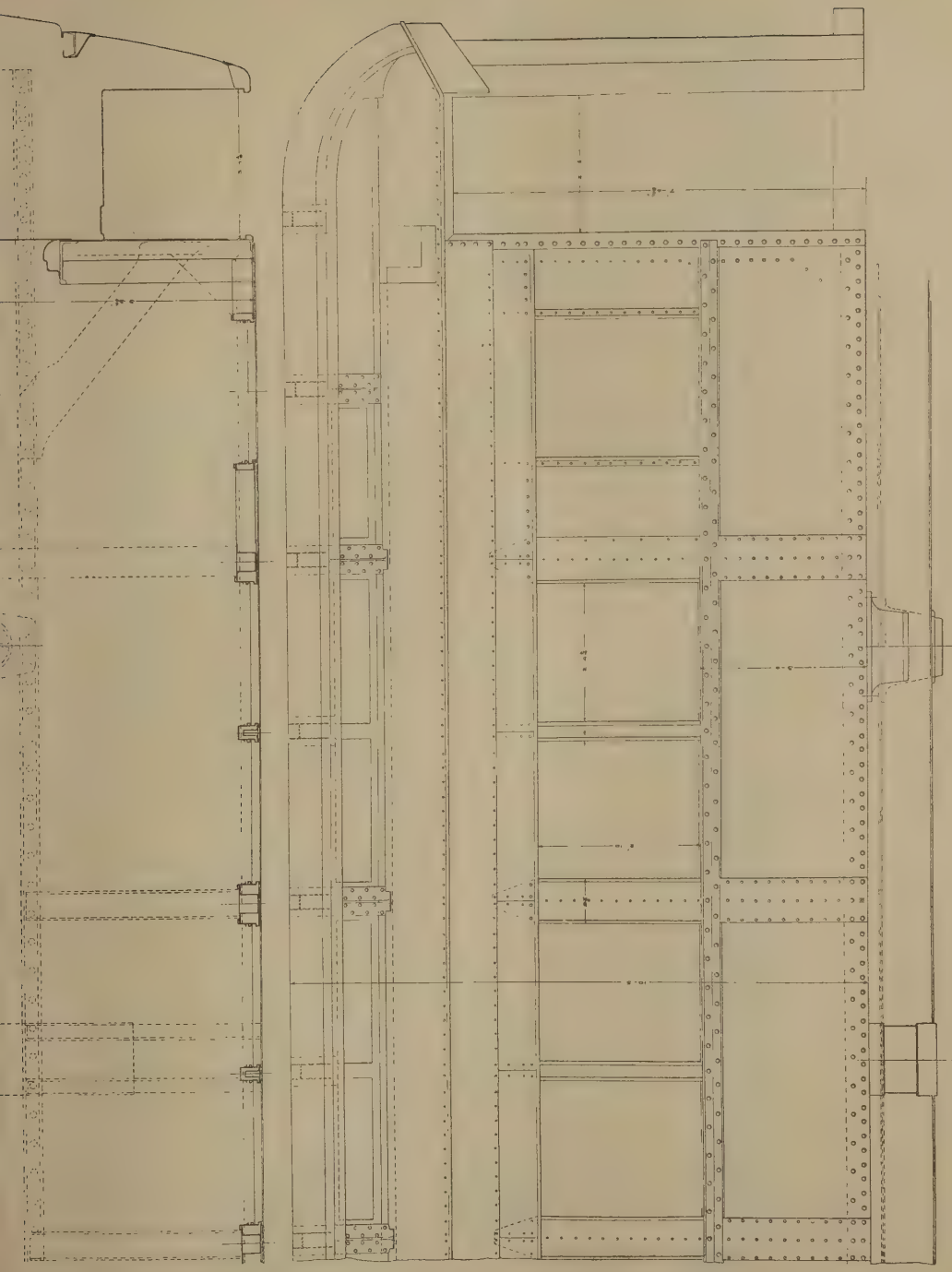
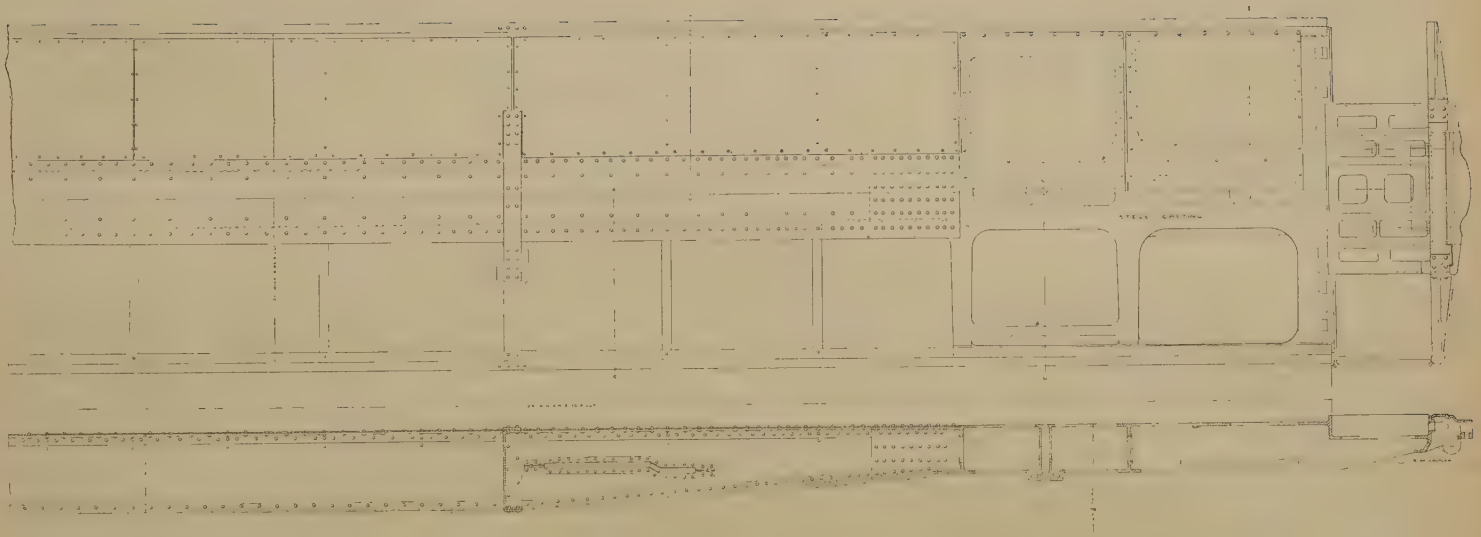
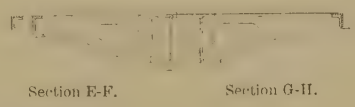


Fig. 59.



Section A-B.



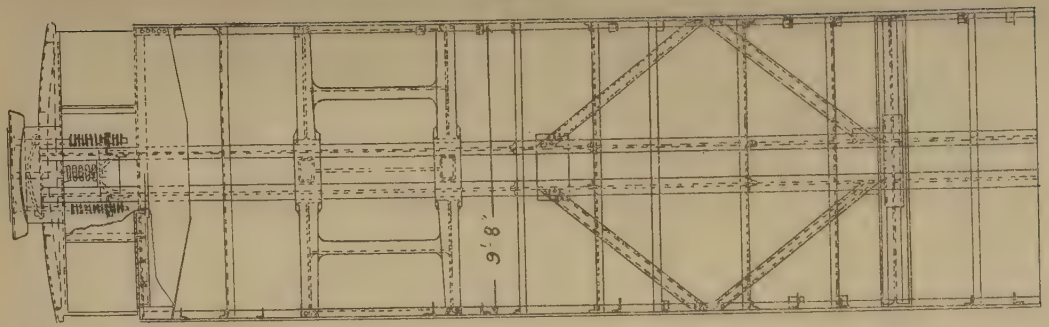
Section C-D.

Section E-F.

Section G-H.

Fig. 60.

Fig. 61.



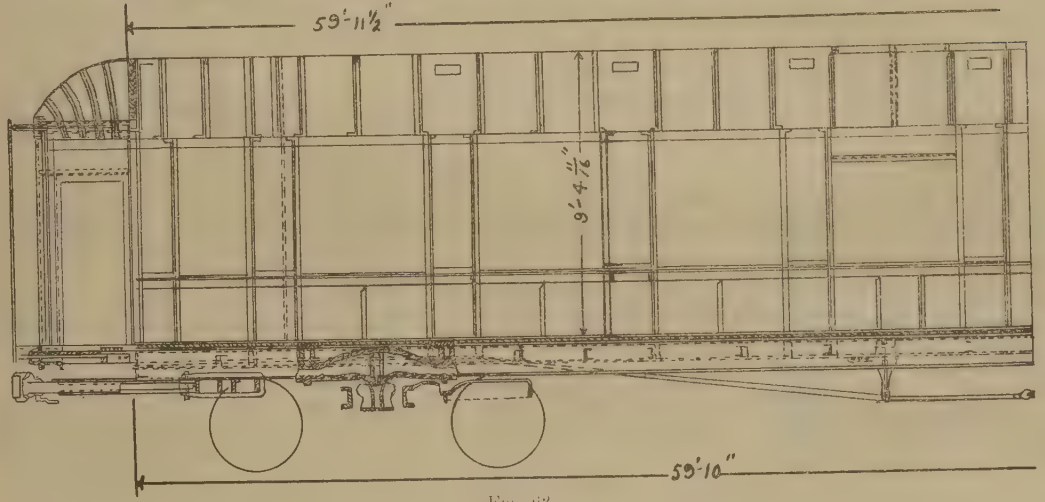


Fig. 62.

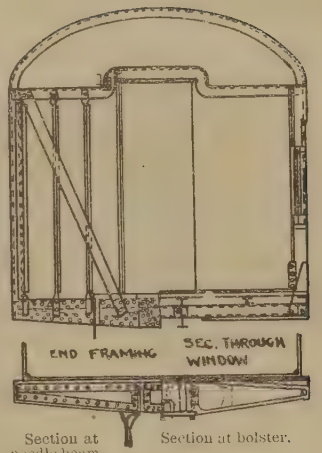


Fig. 63.

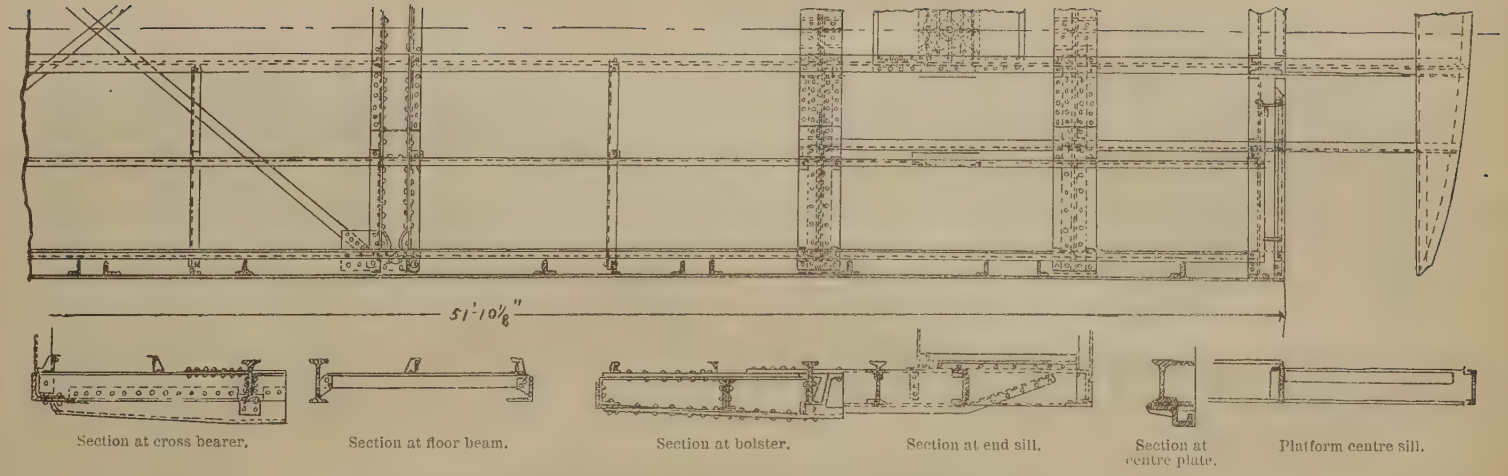

51'-10⅛"
Section at cross bearer.
Section at floor beam.
Section at bolster.
Section at end sill.
Section at centre plate.
Platform centre sill.

Fig. 64.

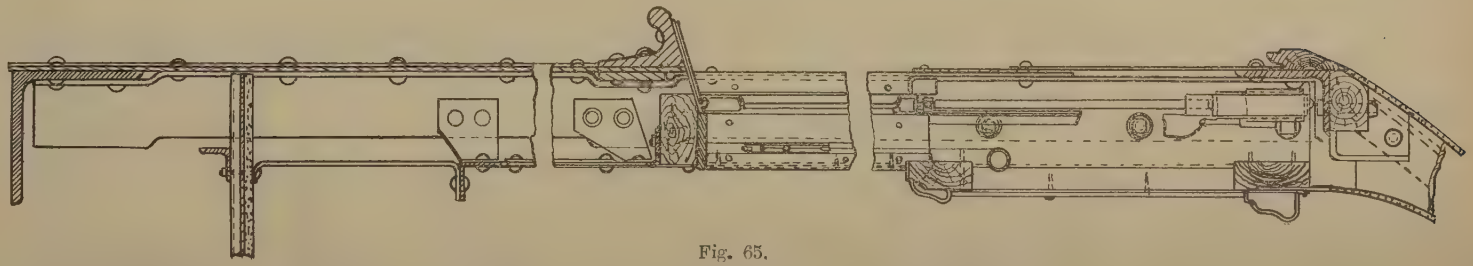
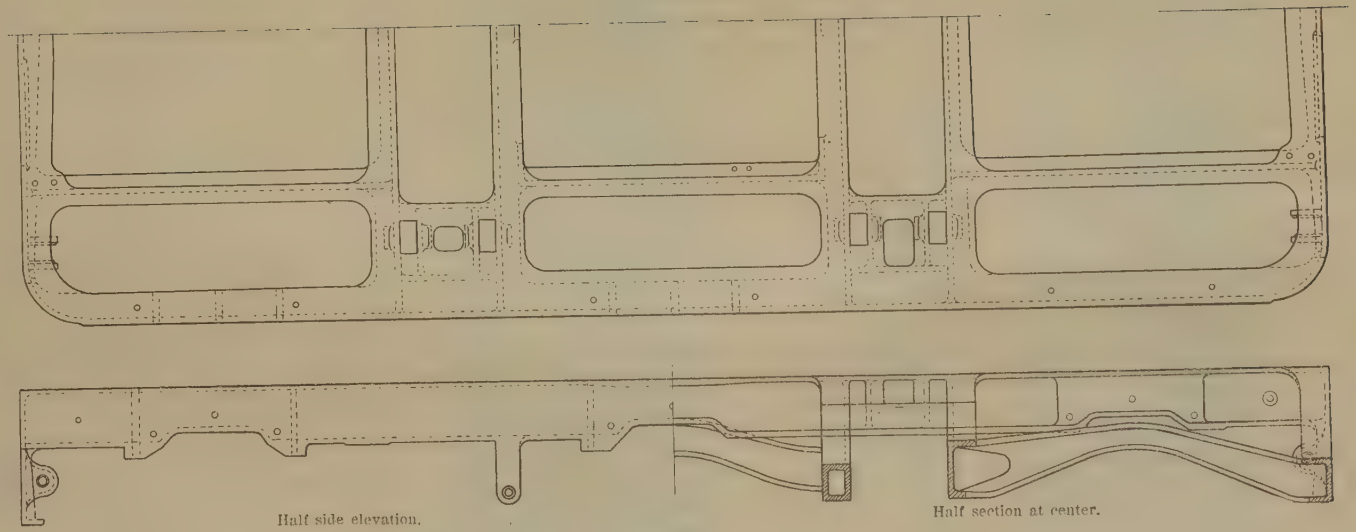


Fig. 65.



Half side elevation.

Half section at center.

Fig. 66.

The quality of steel used in cars constructed for one of the railways is graded as follows :

A. — Thin steel used for mouldings, etc.;
B. — Flattened steel used for outside and inside finishing;
C. — Rolled sheet for general construction of car and trucks;
D. — Rolled shapes.

The requirements for the several grades are given below :

Grade A.

The quality of material for this grade must be such that it can be successfully drawn or pressed cold into mouldings, etc. without rupture. This material when so ordered must have bright finished surfaces entirely free from mill scale and rust, and must likewise be reasonably flat, but need not be leveled. No tests of this grade other than successful working are required.

Grade B.

The material for this grade must be flatened so that the sheets are practically free from waves and buckles. They must be free from mill scale and rust. For all sheets less than 0·10 of an inch in thickness, there are no further requirements. For sheets 0·10 of an inch or more in thickness, the material desired is medium soft steel capable of being formed either hot or cold by pressing. It should have a tensile strength of 60,000 pounds per square inch and elongation of 15 per cent in eight inches.

Grade C.

For sheets less than 0·10 of an inch in thickness there are no further requirements than given under the general specifications. For sheets 0·10 of an inch or more in thickness the material desired is medium soft steel capable of being formed either hot or cold by pressing. It should have a tensile strength of 60,000 pounds per square inch and an elongation of 25 per cent in eight inches.

Grade D.

The material desired should have a tensile strength of 65,000 pounds per square inch and an elongation of 25 per cent in eight inches. The shapes must be straight and true and conform to the drawings in cross section. They must be free from slivers and shall have a full section throughout their length. Material having a cross section area of one square inch or less need not be subjected to physical tests.

These specifications are, of course, based more on the general knowledge of what

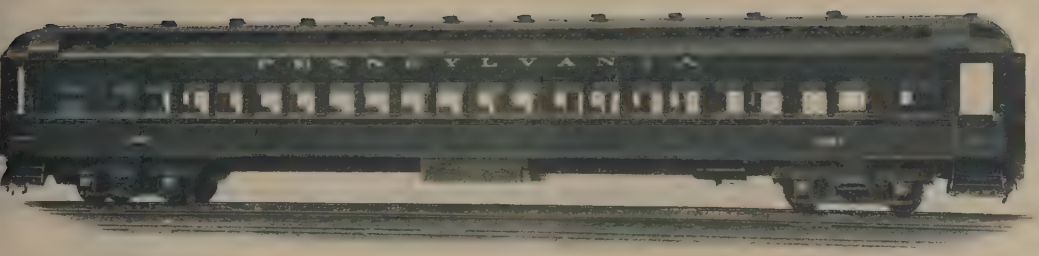


Fig. 67. — All-steel passenger car.

General dimensions :			
Length over platform	80 ft. 3 3/4 in.	Width over side sheets	9 ft. 9 3/4 in.
— — body corner posts	70 ft. 5 3/4 in.	— inside between finish	9 ft. 1 1/8 in.
Distance from center to center of trucks	56 ft. 3 in.	Height from top of rail to top of roof	14 ft. 0 1/2 in.
		Seating capacity	88 persons.

Interior finish, steel.

Fig. 68. — All-steel combination passenger-baggage car.

General dimensions :			
Length over buffer face plates	77 ft. 8 3/4 in.	Width over side sheathing	9 ft. 9 3/4 in.
— over body corner posts	71 ft. 1 1/16 in	— inside between finish, passenger compartment	9 ft. 1 1/8 in.
— inside passenger compartment	34 ft. 9 11/16 in.	— — baggage compartment	9 ft. 0 3/4 in.
— inside baggage compartment	35 ft. 6 in.	Height from top of rail to top of roof	14 ft. 0 1/2 in.
Distance from center to center of trucks	53 ft. 6 in.	Seating capacity	42 persons.
		Capacity baggage compartment	35,000 lb.

Interior finish, steel.

*

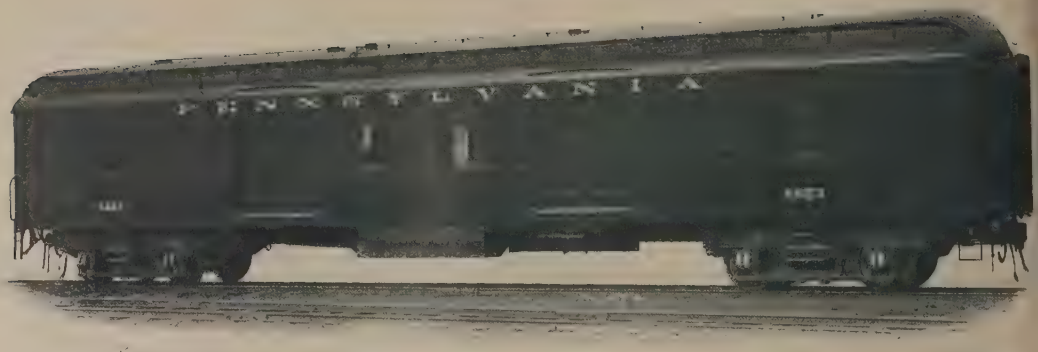


Fig. 69. — All-steel baggage cars.

General dimensions :			
Length over buffer face plates	64 ft. 3 3/4 in.	Width over side sheathing	9 ft. 9 3/4 in.
— — body corner posts	60 ft. 10 3/8 in.	— inside	9 ft. 0 3/4 in.
— inside of body	60 ft. 3 in.	Height from top of rail to top of roof	14 ft. 0 1/2 in.
Distance from center to center of trucks	44 ft. 3 in.	Capacity	35,000 lb.

Interior finish, steel.

Fig. 70. — Steel passenger car.

General dimensions :			
Length over platform	74 ft. 6 1/4 in.	Width over side sheets	9 ft. 10 1/4 in.
— — car body	66 ft. 0 in.	— inside between finish	8 ft. 10 3/4 in.
Distance from center to center of trucks	50 ft. 0 in.	Height from top of rail to top of roof	14 ft. 2 in.
		Seating capacity	72 persons.

Interior finish, mahogany.

The car illustrated above has steel underframe, steel upper structure, steel platform, steel floor and steel sides below windows; the interior finish is of wood. Cars are also built of all steel and non-inflammable interior finish, as may be desired. Steel passenger cars weigh practically no more than wooden cars of same size and equipment.

would seem to be appropriate material than on data obtained from results, either in building and operating the cars, or manufacturing the material, and it is probable that modifications will be made from time to time as experience indicates is desirable.

Cost of cars. — Comparison of the cost of cars of wooden construction 70 feet long between end sills and cars of steel construction of the same length; the cars to be alike in seating capacity, and all details such as couplers, air brakes, vestibules, toilet facilities and electric lighting system, would indicate that at the present time the car of all-steel construction will cost from 16 to 25 per cent in excess of the car of wooden construction. As the price of lumber suitable for the construction of passenger cars continues to increase and as the number of parts made of metal and the weight of the metal parts is increased in the desire to obtain greater strength, there is no doubt but that the cost of cars of wooden construction will be higher than at present, while with the cars of steel construction it is to be expected that the cost will decrease due to the simplification and standardization of the designs, improved manufacturing methods developed by experience and the development of special machinery for producing various parts which are now made with ordinary machinery or by hand.

Cars of the design illustrated in figure 57, fitted complete with seats, toilet facilities, air brakes and electric lighting system cost, at the present time, about 14,000 dollars.

Cost of maintenance. — As a considerable proportion of the cost of maintaining passenger equipment cars is due to the frequent painting and renovation of the interior fittings required, the maintenance cost, while less with the cars of metal construction than that of cars of wooden construction, the difference will not be as great as that between the cost of maintaining freight cars of metal and wooden construction.

The cost of running repairs, other than wheels, will be reduced on account of the large reduction in the number of bolts, the nuts of which must be kept tight, and there will be no shrinkage of parts which loosens the structure sufficiently to cause racking and requiring fastenings to be drawn up frequently.

Life of steel passenger cars. — There is no data available upon which an estimate of the life of a metal passenger car can be based. As passenger cars are painted frequently, for appearance, there is no question as to their having the full amount of protection against rust and corrosion that can be afforded by paint.

Weight and capacity. — From the designs made for passenger carrying cars it has been ascertained that cars of all-steel construction having from three to four times the strength of cars of wooden construction of the same general type, may be built

without undue increase in weight of the car of metal as compared with that of the car of wooden construction.

The weight and capacity of some of the cars mentioned are given in the following statement :

Passengers cars.

Weight and capacity.

Figure.	Lenght.	Material.	Capacity (passengers.)	Weight in pounds.	Weight per passenger, in pounds.
56	53 ft. 8 in.	Wood.	62	93,000	1,480
56	70 ft. 0 in.	Wood.	82	110,000	1.341
57	70 ft. 0 in.	Steel.	88	115,000	1,310

The weight of baggage and mail cars of the design embodying the heavy center sill construction is compared with the weights of cars of wooden construction below :

Baggage and mail cars.

Weight and capacity.

KIND.	Lenght.	Material.	Capacity in pounds.	Weight in pounds.
Baggage	60 ft. 0 in.	Wood.	40,000	73,300
Baggage	60 ft. 0 in.	Steel.	40,000	91,000
Mail.	60 ft. 7 in.	Wood.	...	104.300
Mail	70 ft. 0 in.	Steel.	...	128,500

It is estimated that the weight of the Pullman sleeping car of all-steel construction will be from 145,000 to 150,000 pounds, while a similar car of wooden construction weighs from 125,000 to 130,000 pounds.

Although cars of steel construction are somewhat heavier than similars cars of wooden construction it must be remembered that in designing the all-steel car advantage was taken of the opportunity to provide a stronger car.

It will be noted that the weight per passenger (based on maximum seating capacity) of the steel car (fig. 57) is less than the weight per passenger of the wooden car (fig. 56).

From special records made on a large number of trains of the number of pas-

sengers carried it was determined that the actual average weight per passenger of these two classes of cars in service during periods of normal traffic :

Figure 56 : wood	. . . . .	1,783 pounds per passenger.
— 57 : steel.	. . . . .	1,835 — —

and during periods of abnormal, such as holiday traffic :

Figure 56 : wood	. . . . .	1,675 pounds per passenger.
— 57 : steel.	. . . . .	1,637 — —

Trucks. — For use under passenger cars the general practice in America has been to use trucks having either four or six wheels. These trucks have been constructed of wooden frames with metal pedestals, braces and tie rods, and in some cases the wooden side frames have been reinforced by steel plates bolted to them.

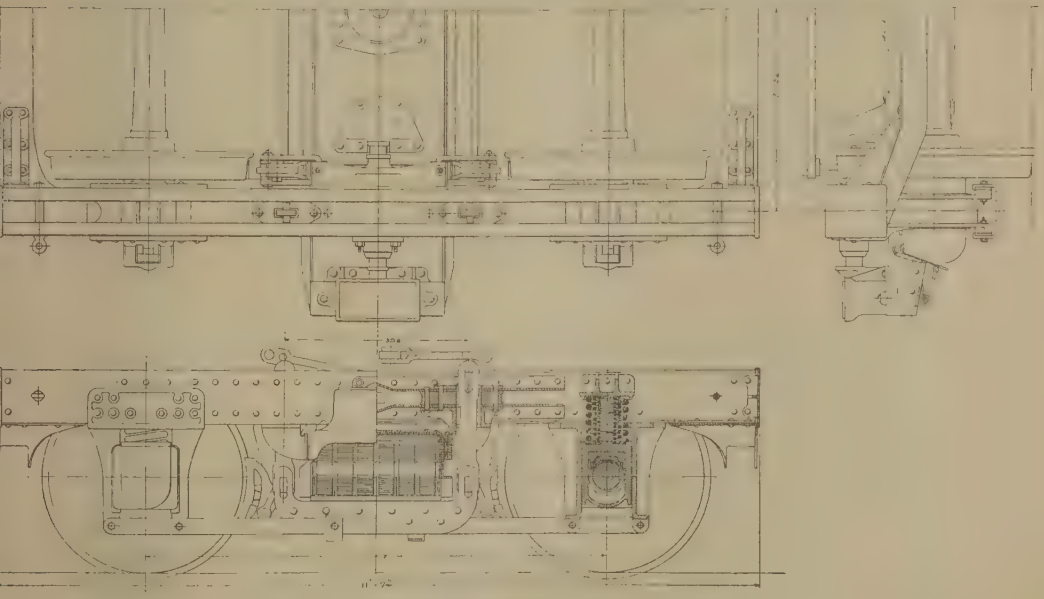


Fig. 71.

Trucks designed to permit the substitution of metal for wood have been considered from time to time, but their use was not extensive. The more general use of steel in passenger car construction, however, has led to the development of the designs for trucks of all-metal construction, and such steel passenger cars as have been built, and those under construction are provided with trucks of all-metal construction.

Figure 71 shows the design of the four-wheel truck used for the all-steel cars illustrated in figure 57. It will be noted that in this truck the frame is made up of rolled and pressed steel shapes and that the number of castings included in the design of the frame is limited to the braces, spring seats and similar parts.

A six-wheel truck of the same general design is used under cars of greater weight than would be permissible with the four-wheel truck.

Figure 66 shows a design of six-wheel truck which is used by several railways for passenger cars. In this design a frame made of steel castings is substituted for the wooden frame previously used; the other parts being modified to conform to the change made necessary by the different material.

A number of other designs of all-metal trucks are used to a limited extent, but the two designs referred to above may be regarded as typical of the design of the majority of such trucks in use at the present time.

In the construction of trucks the use of parts made of steel or steel castings for parts formerly made of wrought or cast iron is increasing. This is considered desirable to increase the strength and to decrease the weight and maintenance costs.

For trucks of similar capacity; say the maximum capacity of the five by nine inch (5 × 9 inch) standard axle, the relative weights of metal frame and steel frame trucks are as follows :

Four-wheel truck : wood.	16,000 pounds.
— — metal (fig. 71).	13,000 —
Six-wheel truck : wood	21,700 —
— — metal (fig. 71).	19,500 —

Trucks of the other design presented approach more closely the weight of the truck with the reinforced wooden frames.

The above would indicate that the use of trucks of all-metal construction will, at least, not add to the weight of the car.

No data is available regarding the relative cost of maintenance of the metal and wooden frame trucks, but, from the experience obtained from trucks in freight car service, undoubtedly the metal truck will be the less expensive.

The solid forged and rolled steel wheels previously referred to in this report are used extensively in passenger car service, although the majority of the passenger cars in use are provided with wheels of the various types having removable steel tires. The use of the cast iron wheel for passenger cars is continued by many railways for the lighter cars.

CONCLUSIONS.

From examination of the designs and construction of the passenger carrying and passenger train cars recently built, and building for the railways in America, your reporter draws the following conclusions :

1° Cars of steel construction will be substituted for cars of wooden construction on account of the former having greater strength, being non-inflammable and less expensive to maintain;

2° The difference in weight of the cars of metal and the cars of wood is not such as would make their use prohibitive from an operating standpoint;

3° As the cost of the cars of steel construction will probably decrease, due to more experience in their design and construction, the cost of cars of wooden construction will undoubtedly increase, due to the scarcity of suitable materials, the use of the metal cars will be extended;

4° For railways using electricity as a motive power the danger of serious accidents will be reduced by the use of the metal cars;

5° The metal structure will better retain its initial strength than any composite structure made up of wood and metal such as the cars of the so-called wooden construction in use to-day.

GENERAL CONCLUSIONS.

1° The present practice in America in the construction and designing of locomotives, freight cars and passenger cars is to use steel either of rolled or pressed shapes, or steel castings for many parts, extending to practically the complete car;

2° The progress made in design and manufacture in steel of the various details of locomotives and cars, such as tubes, wheels, bolsters, truck frames, and similar parts, indicates that further substitution of this material for wood, wrought and cast iron may be expected;

3° While steels of special alloy or composition have been utilized in the building of railway rolling equipment, neither the quantity used nor the length of time in service is sufficient to warrant any expression as to the possible economy to be obtained by their use;

4° The use of steel construction of railway rolling equipment has generally given advantageous results, both from a service and economic standpoint, as compared with the results obtained with the material for which it was substituted.

APPENDIX.

PENNSYLVANIA RAILROAD.

LINES EAST AND WEST OF PITTSBURGH.

(No. 60. Issued, Altoona, Pa.)

General specifications for steel passenger equipment cars.

General requirements. — The car must be built in the best, most substantial and workmanlike manner, according to the true intent of the specifications and drawings furnished, which are intended to include everything requisite to the proper building of the cars, notwithstanding that everything required may not be mentioned in the specifications. The drawings and specifications are intended to explain each other, and when anything is shown on drawings but not referred to in specifications, or when anything is referred to in specifications but not shown on drawings, the same shall be considered as being shown or referred to. When delivered, everything must be complete, and the cars must be ready for service.

Drawings and specifications. — A complete set of drawings, a copy of list of tracings, and material specifications will be furnished by the General Superintendent Motive Power for each contract, and no deviation from drawings or specifications will be allowed, except by authority, in writing, from the General Superintendent Motive Power.

Detail specifications. — The detail specifications for material are as follows :

Specification Number.	Material.
9	Bar iron.
10	Axles.
11	Chains.
12	Helical springs.
13	Elliptical springs.
37	Tuscan red.
38	Spirits of turpentine.
39	Galvanized iron.
44	Air brake hose.
	Steam hose.
45	Waste.
46	Plush.
53	Mixing freight car color.
54	Incandescent lamps.
55	Air signal hose.
84	Mixing of tuscan red.
59	Steel for metal passengers cars.

INSPECTION.

Inspection at place of manufacture. — Castings, steel plates, wheels, axles, journal boxes, journal bearings, wedges, chains, springs, brake wheels, centre plates, plate glass, steel doors, and composite board will, whenever possible, be inspected and tested at the place of manufacture.

Inspection at Altoona. — Paints, bar iron, waste, journal bearings, and hose will be tested at Altoona, where samples must be sent.

Each car will be inspected during its construction, and after its completion, by representatives of this Company, who may also inspect all parts to see that they conform to the drawings and specifications, and any materials or cars which do not conform will be rejected.

TRUCKS.

Wrought iron details. — The following details must be made of wrought iron : Spring carrier, spring carrier hangers, brake clog hangers, brake rods and brake levers. All rivet holes must match without drifting, and rivets, after they are driven, must completely fill the holes.

Journal bearings. — Journal bearings will be furnished by the Pennsylvania Railroad Company.

Stop wedges. — Stop wedges and centre plates must be drop-forged steel, and must conform to gauges.

Journal boxes. — Journal boxes must be made of cast iron to conform to gauges, fitted complete with dust guards and box lids, and must be well packed with wool waste, thoroughly saturated with Galena coach oil.

Axles. — Axles must each be stamped on one end with letters designated by the Pennsylvania Railroad Company, to show who are the builders of the truck, and with figures to show the date when put in service.

Burnishing journals. — The journals and wheel seats must be finished smooth, and true to gauges, before the weels are mounted; the journals must be burnished.

Wheels. — Both wheels on each axle must caliper alike, and must not vary in diameter more than $^1/_{32}$ inch. Wheels must be pressed on the axles at a pressure of not less than fifty tons, and not more than seventy tons.

Springs. — Springs must be selected to suit each weight of car.

Truck frames. — The truck frames must be perfectly square, and must have no hand-driven rivets.

Truck bolsters — The truck bolsters must be of pressed steel, reinforced with angles and plates of the form and dimensions shown on drawings, and of material tested in accordance with Pennsylvania Railroad specifications.

Stenciling. — The initials and number of the car, and figures designating the class of bolster springs, must be stenciled on each side of the bolster.

Side bearing cushion. — A sheet of rubber $^1/_4$ inch thick must be placed in each side

bearing pocket of four-wheel trucks underneath the bearing plate, and the bearing plate must be of such thickness that this rubber is well compressed when body of car rests on trucks.

BODY.

Underframe. — The centre girders must be riveted together, with sufficient camber to insure absence of sagging when car is complete.

End casting. — The end casting must be so located that the top and front faces are in correct position relative to top flanges of centre channels.

The specified distance between inside face of knuckle and vertical face of end casting must be closely followed.

The bottom face of centre plate backing casting must project $^1/_{64}$ inch below lower flanges of centre sill channels, to insure proper contact with bottom cover plate.

Air brake. — The cars must be equipped with Westinghouse air brake, high speed reducing valve, and American automatic slack adjuster, form J for 14 or 16 inch cylinders, and form K for 18 inch cylinders, as per drawings furnished.

Superstructure. — The outside plates must be perfectly flat, and drilled to template. All exposed rivet heads must have the special shape, shown on drawings.

All exposed butt joints must be soldered.

Acid dropped on sheets must be carefully removed, to prevent rust from forming under the paint.

Canvas soaked in white lead must be placed against deck plate, underneath deck sash frame and lower roof plate flange.

Window facing brackets attached to posts must be faced, drilled and tapped to jig, so that the window sash will be interchangeable.

The flooring, inside of car and on platform, must consist of monolith, or its approved equivalent, laid on metal, provided with clips spaced about 8 inches apart, and must not weigh more than fifty pounds per square yard.

The saloon floors must be covered with asphalt, according to the following formula :

25 pounds asphalt;
122 — . grit;
203 — neuchatel.

This material should be thoroughly boiled, and applied while hot.

Inside lining. — All plates must be perfectly flat and smooth, and free from rust or scale. Ceilinite $^3/_{16}$ inch thick must be glued with fire-proof glue to the back of all flat surfaces. The ceiling must consist of non-inflammable composite board, or its approved equivalent, held in place by means of metal straps, and special shaped bolts and nuts, as per drawings.

HEATING AND VENTILATING.

The cars must be equipped with hoods, downtakes, ducts under floor, air passageways through floor, and heater boxes, as per drawings.

The heating arrangement must include all necessary traps, inlet valves, end valves, hose and couplers, and must be tight under a steam pressure of 100 pounds.

LIGHTING.

All cars will be electrically lighted from train generators or storage batteries.

Batteries. — Each car must be equipped with a storage battery consisting of thirty-two cells, each of two hundred and eighty ampere hour capacity. The cells must be arranged in two-compartment lead-lined tanks, all substantially as shown on standard tracings.

Each cell must contain six positive and seven negative plates, each approximately 7 3/4 inches wide by 10 inches high. The positive plates must be made from 17 pound lead, and both positive and negative plates must be formed by the so-called plante process.

The batteries must be furnished complete, including elements, separators, insulators, tank linings and hand connectors, and must be fully formed, charged, and ready for service when applied to the car.

Conduit. — The conduit must be steel pipe, galvanized inside and outside, and must be of a quality approved by the railroad company.

All conduit must conform to the following table of weight and dimensions when delivered at the point where same is to be used. A maximum variation of five per cent. below the respective weights will be allowed.

	Diameter of conduit.		*Thickness of metal.*	*Weight per foot.*
Nominal.	External.	Internal.	Inches.	Pounds.
1/2 inch.	0·84	0·62	0·110	0·85
3/4 —	1·050	0·824	0·113	1·115
1 —	1·315	1·047	0·134	1·168
1 1/4 inches	1·660	1·380	0·140	2·244
1 1/2 —	1·900	1·610	0·145	2·670
2 —	2·375	2·067	0·154	3·609

All conduit must be furnished in lengths of at least 10 feet, and with each length one coupling. If desired, the car builders may order the conduit cut to specified lengths.

The interior of the conduit must be smooth and free from burrs and fins. All conduit must be carefully examined before installation, and blistered or defective pieces rejected.

The ends of all conduit must be cut square and reamed.

All conduit must be installed in a first-class manner and all joints brought to a shoulder and made water-tight.

All conduit connections to junction and other boxes where screw connections are not shown, must be provided with approved lock nuts and bushings.

No lubricants other than ivory soap or soap-stone may be used to facilitate pulling wires into conduit.

Wire, general. — All wires will be used to carry current at a normal working potential of 80 volts, with a possible maximum working potential of 90 volts.

All workmanship and material must be first-class and the best of their respective kinds.

Conductors. — All wires smaller than No. 6, B. & S. gauge, must be solid conductor, and all wires No. 6, B. & S. gauge, and larger must be stranded. Each solid conductor or strand of the stranded conductor must be of soft drawn annealed copper having a conductivity of not less than 98 per cent pure copper, Matthiessen's standard, must be continuous throughout its length, and must be provided with a heavy uniform coating of tin without burrs or fins.

*

Physical tests. — The wire must be capable of an elongation of 25 per cent of its length in 10 inches without breaking, and must stand, without breaking, thirty twists in 6 inches. It must also be capable of being wound 6 times about a wire of its own diameter and then unwound.

The above tests are to be made on separate pieces of wire.

Varnished cambric insulated wires. — Train line wires must be composed of 37 strands of No. 14 B. & S. gauge wire giving a cross section of 151,700 C. M., and having a bare outside diameter of 0·45 inch, and a diameter over the insulation and braid of 0·66 inch.

The 4-0 wire connection to automatic switch must be composed of 91 strands, each strand being 0·048 inch in diameter, giving a bare diameter of wire of 0·53 inch, and a diameter over the insulation and braid of 0·75 inch.

The 3-0 wire for the flexible connection between cars must be composed of 259 strands, each strand being 0·0253 inch in diameter, giving a bare diameter of wire of 0·53 inch, and a diameter over the insulation and braid of 0·75 inch.

The above wires must be covered with varnished cambric cloth or other approved insulation and a single cotton braid $^1/_{32}$ inch thick with weather-proof finish to make the respective outside diameters given above.

Rubber insulated wires. — All other wires must be insulated with rubber compound and protected with double cotton braid. This braid must be saturated with a compound of such quality as will not be injurious to the cotton nor to the rubber. The conductor shall be insulated concentrically to the thickness of wall indicated with a rubber compound of such quality as will successfully meet all requirements specified below.

Physical tests of rubber. — A strip of compound 4 inches long, taken evenly and smoothly from any conductor must pass the following physical tests. A marked section 2 inches long, after being stretched to 6 inches and immediately released must return within one minute after release to 2 $^3/_4$ inches, and must thereafter stand an ultimate elongation to 7 $^1/_2$ inches before breaking.

Voltage test. — Each length of insulated conductor must withstand for a period of two minutes, after twenty' four hours immersion in water, and while still submerged, voltage tests as specified, from apparatus as required by the American Institute of Electrical Engineers.

Insulation resistance test. — After having successfully passed the specified voltage test, and while still submerged, the conductor must show, after one minute electrification by an E. M. F., of not less than 100 volts, insulation resistance not less than the specified megohms per mile at 60° Fahr.

Rubber insulated wires Size.	Thickness of insulation wall.	Strands.	Volts test.	*Insulation resistance.* Megohms per mile at 60° Fahr.
4 Stranded	$^1/_{16}$ inch.	7	3,000	400
6 Stranded	$^1/_{16}$ —	7	3,000	500
8 Solid	$^3/_{64}$ —		3,000	800
10 Solid	$^3/_{64}$ —		3,000	900
12 Solid	$^3/_{64}$ —		3,000	1,000
14 Solid	$^3/_{64}$ —		3,000	1,000
Cambric insulated wires				
All sizes			3,000	50

Acceptance. — Material failing to meet the requirements of these specifications will be rejected by the Company's accredited representative, and returned to the manufacturer at the latter's expense.

PAINTING.

All surfaces throughout car must be thoroughly cleaned, and must be free from scale, rust, grease or acid when paint is applied. Sand blast should be used if necessary. Each coat of paint must be dry before succeeding coat is applied, and must be of approved quality.

Trucks. — Before assembling, all surfaces on truck parts throughout, including all concealed surfaces, but not including wheels and axles, must be covered with one coat of good metal preservative paint.

After assembling, all surfaces exposed to view after body of car has been placed on trucks, except wheels, must be covered with two coats of truck enamel.

Underframes. — During the process of construction, all parts of the underframe, including concealed surfaces, and surfaces where metal bears on metal, must be covered with two coats of good metal preservative of a non-inflammable nature. All accessible surfaces must be covered with a third coat of metal preservative coating when the structure is completed.

Superstructure. — Before assembling, all parts made of iron or steel, including roof, must be covered with one coat of primer. A second coat of primer thinned with one quart of turpentine to one gallon of compound must be applied to all surfaces, including those which are concealed when car is completed. Wherever possible, this second coat must be put on after the sheets are riveted in place.

After assembling, the outside of side and end sheathing, including letter plate and deck plate, must be covered with one coat of surfacer, glaze the rough and uneven places with « Surfacer Composition », then add four coats of surfacer, rub down with linseed oil and emery cloth, add two coats of Tuscan Red, followed by striping and lettering, then finish with three coats of finishing varnish.

The outside of the roof must be finished with two coats of Pennsylvania Railroad freight car color.

For passenger cars and passenger end of combined cars, the inside lining above windows, deck plate, and saloon doors, inside of end doors, aisle partitions of saloon and compartment opposite and inside of saloon to floor must be finished in bronze color according to the following formula :

Brass bronze	4 lb.
French yellow ochre in oil	2 lb.
Burnt sienna in oil	1 1/4 lb.
Lamp black	5/16 lb.
Rubbing varnish	3/8 gallon.
Japan	1/8 —
Turpentine	3/8 —

Painting should be continued, as follows : Putty, glaze, and rub down with linseed oil and emery cloth. One coat of ground color, according to the following formula :

French yellow ochre in oil	3 lb.
Lamp black in oil	1/16 lb.

Raw linseed oil	1/8 gallon.
Japan	1/16 —
Rubbing varnish	1/16 —
Turpentine	3/8 —

One coat of bronze color, which should be strained and well stirred while using; this must be laid on evenly and stippled. Four coats of rubbing varnish; when thoroughly dry, rub down with pumice stone and oil.

The window sills, side lining below window sills, metal seat frame complete, and heater boxes must be painted bronze green, according to the following formula :

Medium chrome yellow in oil	8 lb.
Lamp black in oil	4 lb.
Rubbing varnish	1/2 gallon.
Japan	1/8 —

Thin with turpentine.

This should be applied, as follows : Two coats of color; three coats of rubbing varnish; when thoroughly dry, rub down with pumice stone and oil.

The headlinings and saloon ceilings to be painted pale green, according to the following formula :

White lead	25 lb.
Medium chrome green in oil	5/8 lb.
Medium chrome yellow in oil	1/4 lb.
Raw umber in oil	1/4 lb.
Raw linseed oil	1/8 gallon.
Rubbing varnish	1/4 —
Japan	1/32 —
Turpentine	1/4 —

This should be applied as follows : One coat of priming mixed with headlining green—use 1/8 gallon green to each gallon of surfacer ; putty, glaze, and sandpaper. Two coats of headlining, green, laid on evenly and stippled. The last coat should be applied after the sides are finished.

The floor to be painted according to the following formula :

French yellow ochre in oil	16 lb.
Burnt umber in oil	8 lb.
Rubbing varnish	1/4 gallon.
Japan	1/4 —

Thin with turpentine.

This should be applied as follows : Two coats of floor color; one coat of orange shellac.

The window sash and seat arms should be finished in natural mahogany, and the deck sash, frames should be painted and grained to correspond in color.

For baggage cars : The inside lining must be painted as follows · One coat enamel primer dark; two coats of drab enamel.

The ceiling must be painted as follows : One coat enamel primer, white; two coats of white enamel.

The floor must be painted as follows : Two coats of elastic floor paint, dark red.

For postal and storage cars, the inside lining must be painted as follows : Two coats of oak ground color—grain and stipple; one coat of varnish.

The ceiling must be painted as follows : One coat of enamel primer, white; two coats of white enamel.

The floor must be painted as follows : Two coats of elastic floor paint, dark red.

Steel. — Steel must be made by the open-hearth process, and must conform to separate specification. Sheets for sheathing and lining will be inspected for surface, flatness on loading on cars.

Wrought iron. — The material under this heading will be ordered as « Bar iron, » and must conform to separate specification.

Forgings. — All iron required for forgings must be of the quality above specified, and must be capable of being worked at proper heat without injury.

Cast iron. — All gray iron castings shall be made of tough gray iron, which shall exhibit a uniform and closely-grained fracture, free from any white, mottled or vitreous appearance. It shall be soft enough to be readily cut, drilled and chipped; and when struck on a corner or edge with a hammer, the metal shall indent and not break off.

Malleable iron. — Malleable iron castings must be of a clean, high-grade metal, evenly annealed throughout. When required for test, specimens of the annealed iron used for castings shall be furnished by the contractor. Such specimens shall show upon a test an ultimate strength of 40,000 pounds per square inch, an elongation of at at least 2 $^1/_2$ per cent. It shall be capable of bending to an angle of 80° without showing a fracture on the convex side. All castings to be of shapes required, and to be lettered and numbered as indicated.

Cast steel. — All steel castings shall be annealed. If required, the steel castings shall be made with a coupon for testing, which shall be cut off after annealing, and the test shall be made from a $^3/_4$ inch round cut from the coupon. The test piece shall show an ultimate strength of at least 70,000 pounds, and an elastic limit of not less than 35,000 pounds, and elongation of at least 15 per cent in 2 inches, and a reduction of area of 20 per cent at the point of fracture.

When the bearing surface of any steel casting is finished, there shall be no blow-hole visible exceeding 1 inch in any direction, nor exceeding $^1/_2$ square inch in area. The length of blow-holes, gauged by any straight line in any direction, shall never exceed 1 inch in one foot.

Glass. — All glass intended for use in side windows of passenger carrying compartments must be polished plate-glass, $^1/_8$ inch thick.

All glass for end doors, vestibule side doors, and end windows, must be polished plate-glass, $^1/_4$ inch thick.

All window glass in postal, baggage and express cars, and in all compartments, except passenger compartments of combined cars, must be double-thick crystal glass.

Notices. — Standard Pennsylvania Railroad practice must be followed in design and location of notices in cars.

Brass trimmings. — All brass trimmings must conform in color to samples furnished, and must have a scratch brush finish. The lamps, basket racks, and all fittings above top window line must be lacquered.

Hand railings. — Hand railings in vestibule and outside of car body must have all roughness removed, and must be japanned.

A list of specialties will be furnished for each order of cars.

A. W. GIBBS,
General superintendent motive power,
Pennsylvania Railroad Lines East of Pittsburgh.

D. F. CRAWFORD,
General superintendent motive power,
Pennsylvania Lines West of Pittsburgh.

February 18, 1908.

[621 .131.2 & 625 .246]

REPORT N° 4

(America)

By R. L. ETTENGER,

CONSULTING MECHANICAL ENGINEER, SOUTHERN RAILWAY.

The Permanent Commission of the Railway Congress having instructed me with the preparation of a report on, the use of special steel of high resistance in the making of various parts of locomotives and rolling stock. The following detailed list of questions were sent to the affiliated lines and replies received from forty-nine Companies :

LIST OF QUESTIONS.

—

AXLES.

1. *In your change from the use of iron axles to steel axles, did you purchase to test and specifications ? If furnished to specification can you give a copy or the required chemical analysis and drop test ?*

2. *In changing to your present specifications what change in chemical analysis dit you make ?*

3. *Have you used any axles of special composition or alloy such as chromium, nickel, vanadium, etc. ? If you have, can you give the analysis, and tensile strength, the drop test, and effect of same ?*

4. *How long have the special axles been in service and under what weight and size of journals ?*

On Locomotives.
On Cars.

*

5. *Are the special axles you are using only experimental or will you use them on all heavy equipment?*

6. *Please give the general results you are obtaining from the use of high grade steel in car and locomotive axles and the analysis and result of physical test of the axles that have given the best satisfaction.*

BOILERS.

1. *Do you use boiler and fire box steel made to your own specification, or rely on the maker and brand only?*

2. *Do you use any other than open hearth steel?*
Do you use acid or basic steel or both? What difference do you find in service?

3. *Please furnish a copy of your specifications for boiler steels and give the average results of physical test, particularly the elastic limit, with ultimate strength and elongation.*

4. *Have you experimented with or used any special steels of great strength alloyed with nickel, vanadium, etc.? If you have, please give the results obtained and the analysis of the steel. Has the special alloy steel produced the results expected and will you continue its use?*

5. *Please give analysis and physical properties of the steel you have found to give the best results in fire boxes of high pressure boilers, the average life of fire boxes with the best steel, and the average water use, whether good, fair or poor.*

6. *Have you had occasion to reduce the weight of boiler sheets to a minimum to get the engine wanted within the weight allowed? If you have, please give the factor of safety used, the steam pressure carried and the specification for steel. How long have such boilers been in service and what results have you obtained?*

SPRINGS.

1. *Do you purchase car and locomotive springs under specification for the steel or of given size and capacity only? Do you use open hearth or crucible steel? Have you used springs made from special alloy steel, and particularly vanadium?*

2. *Please give analysis and physical test of the steel which has given the best results in driver springs.*

In truck springs?
In draft springs?

If you have used springs made from special high-grade steel, please give any information you can with regard to the manufacture, temper, working conditions and results obtained.

TIRES.

Please include in your reply, steel tires for both locomotives and cars also solid steel wheels.

1. *Do you purchase tires to specification covering analysis and physical properties of the steel?*

If so, please furnish copy of your specifications. Have you used any tires made from special high grade steel?

Open hearth or crucible?
What analysis?
What physical test?

2. *If you have used any special tires, please state what service they are in, locomotive of cars. The diameter of the wheels, weight on each pair of wheels and mileage made per $^1/_{32}$ inch wear.*

3. *How many tires of the special high grade steel have you in service? Will you continue their use? If not, why?*

Please give a comparison between the service obtained from the special high grade tires and those of ordinary manufacture, and ablue print showing cross section of the tires as applied.

FRAMES.

1. *Do you use cast steel locomotive frames? Please furnish chemical analysis and physical properties of the cast frames you have found to give the best results.*

2. *Have you experienced trouble from cast steel frames breaking and been able to overcome the trouble by getting frames of special high grade steel? If so, please give full analysis and test of the broken frames and in those used in replacement.*

3. *Have you used any frames of nickel, chroimum or vanadium steel? What results? Please give full particulars.*

4. *To what extent have you been benefited by the use of high grade steel in frames for locomotives, including weight, design and repair?*

PISTON RODS, CRANK PINS AND CONNECTING RODS.

1. *Please furnish copy of your specifications for billets or rough forgings for the above parts.*
If you re-heat the forgings what heat treatment is given?
Have you used regularly or experimented with, special high grade steels for these parts?
If you have, please give full analysis and physical properties with results gotten in service.

2. *Did you use the special high grade steel to be able to lighten the forging, or because you were having trouble from failures?*
What was the result?
Do you expect to continue the use of the special steels and to what extent?

DRAWINGS.

It will be much appreciated if blue prints will be furnished, showing the old and new design, where forgings and castings have been lightened or cheapened by the use of special high grade steels.

The text of the question does not indicate clearly at what point steel should be considered as being special or of high resistance, and, as it is obviously desirable that the interpretation be the same for all the reporters, the Managing Committee, after reviewing the correspondence, suggested the reporters accept as a minimum 85,337 pounds per square inch for forgings and 114,000 pounds per square inch for springs — and consider as being of high resistance, steels of greater tensile strength.

Axles for cars.

Examination of a large number of records showing the tensile strength of axles made for cars of 60,000, 80,000 and 100,000 pounds capacity, show the average axle made to stand the American drop test and to meet the required chemical composition, to have a tensile strength equal to or exceeding our minimum of 85,337 but as these axles are made to a specification with a tensile strength requirement having a minimum of 80,000 pounds, they will not be treated as special steels.

During 1899 the Bessemer & Lake Erie Railroad Company ordered one thousand cars of 80,000 pounds capacity, the axles for which were made of nickel steel, these axles are still in service, and are the only axles of special steel that have been reported as used under this class of equipment.

In the manufacture of these axles there were thirty-eight heats tested for chemical analysis and one axle from each of the heats tested under the drop with results as follows :

Size of axles.

Journals	5 × 9 inches.	Diameter at centre	5 3/8 inches.
Height of drop	44 feet.	Weight of drop	1,600 pounds.

Average analysis.

Carbon	0·26 per cent.	Silicon	0·021 per cent.
Phosphorous	0·011 —	Nickel	3·31 —
Manganese	0·77 —		

Average physical.

Elastic limit, lb. per square inch	57,030	Average number of blows at which axle started to open	39
Tensile strenght, lb. per sq. inch	87,640	Average number of blows at which axles broke	67
Per cent elongation in 2 inches	30		
Per cent reduction of area	56·2		

Of the thirty-eight test axles the best record was from heat No. 1245 :

Carbon	0·28 per cent.	Elastic limit, lb. per square inch	63,560
Phosphorous	0·008 —	Tensile, lb. per sq. inch	101,050
Manganese	0·75 —	Number of blows at which axle broke	77
Silicon	0·017 —		
Nickel	3·23 —		

Of the thirty-eight text axles the poorest record was from heat No. 1210 :

Carbon	0·25 per cent.	Elastic limit, lb. per square inch	57,190
Phosphorous	0·011 —	Tensile, lb. per sq. inch .	85,620
Manganese	0·79 —	Number of blows at which axle broke	54
Silicon	0·022 —		
Nickel	3·00 —		

Axles for locomotives.

The same reference may be made to the average tensile strength of locomotive axles as to car axles, the specification to which they are made in nearly every instance having a minimum tensile strength requirement of 80,000 pounds per square inch while the finished axles will average much higher.

On account of the size of axles for locomotives no drop test is used, the analysis being taken from borings which, with the tensile strength coupons, hammered out on the end, constitute the usual limit of test.

In tabulating the reports from the companies answering, twelve show experiments with special heat treated steels, but in no case have I been able to get a record of the physical properties except from the hammered test bar.

The special steels reported consist of nickel, chrome and vanadium with very few of the vanadium axles in use and no report of their composition or performance.

One Company reports nickel steel axles in use four years without failure, the steel carrying 3 ½ per cent nickel, another Company reports the extensive use of nickel steel axles with 3 per cent nickel and 25 per cent elongation, 55,000 pounds elastic limit, and 85,000 pounds tensile strength per square inch as giving satisfactory service and with fewer failures than with carbon steel. Five Companies reporting nickel axles applied to 240 locomotives, the minimum tensile strength requirement being 90,000 pounds, are not renewing axles of this composition and report more failures of nickel axles than of carbon axles. There is no encouragement shown by the Companies reporting to continue the use of nickel in axles and, with one exception, the larger roads report such numerous failures with the special alloy steels that their purchase has been entirely discontinued.

A summary of all reports received indicates that the experiments made with alloy steels for locomotive axles have not resulted in a betterment of the service or a freedom from failures due to hot boxes, cut journals, and causes of engine delays, but that nickel steel has rather contributed to these failures.

The average size of the journals (which are on straight axles) of the axles reported are 9×12 inches with a weight of 50,000 pounds per pair of wheels.

Boilers.

It does not appear that any experiments have been made in boiler construction using steel of high tensile strength.

Springs.

Previous to about 1900 the general practice was to use crucible steel entirely in the manufacture of car and locomotive springs. Extensive experiments about that time demonstrated that open hearth steel would take less of a set under high fibre stresses than the crucible steels and has been generally adopted. Springs at the present time are largely made to the following analysis :

Carbon	1 per cent.	Sulphur	0·05 per cent below.
Manganese	0·45 —	Silicon	0·25 —
Phosphorous	0·05 — below.		

None of the Companies reporting have used special steels in the manufacture of springs until within the past year. There has been chromium vanadium alloy steel experimented with, which, in the test machines, has shown remarkable results.

Some of the vanadium springs have recently been applied to locomotives, but none of them have been in service a sufficient time to justify a report of their permanent value.

An average analysis and physical test of the chromium vanadium spring steel is as follows :

Chemical.

Carbon	0·45 per cent.	Chromium	1·25 per cent.
Manganese	0·90 —	Vanadium	0·18 —

Physical.

—	Elastic limit, lb. per sq. inch.	Tensile strenght, lb. per square inch.	Ratio, per cent.	Elongation in 2 inches, per cent.	Contraction of area, per cent.
Normal	101,900	162,400	62·7	13	44
Annealed 800° centigrades.	82,600	114,800	71·5	30	63
Oil tempered.	221,000	235,000	93·8	10	39

Nota. — Apparent coefficient of safe working load = 40,000 lb.

Tires.

To be treated as special steel if the tensile strength per square inch exceeds 114,000 pounds would include the average tire in all classes of service and all tires in switching service, the usual specification being as follows :

Chemical limits.

Silicon	0·20 per cent.	Phosphorous.	0·05 per cent.
Sulphur	0·05 —	Manganese	0·80 —

Physical.

—	Passenger engines.	Freight engines.	Switch engines.	Other wheels.
Tensile strength square inch not less than, in lbs	100,000	110,000	120,000	110,000
Elongation in 2 inches, in per cent. .	12	10	8	10

One large System in the East report a number of tests of special tires, some having the surface hardened by the Harvey Process, others of nickel-steel, and steels of special composition, but the results of the test have not been satisfactory, and no details are given showing the composition of the metal.

A large System in the West report six engines with vanadium tires, but de not give other data, except the tires have not been in use long enough to make a comparison. These tires are operating in a mountainous country with ruling grades of 2·2 per cent, one of which is 48 miles in length. The average wear of tires in this territory is 8,100 miles per $^1/_{32}$ inch reduction.

A report of chrome-vanadium tires with twenty-two in use in car wheels in freigh and passenger service, with weight of 38,250 pounds per pair of wheels show a mileage of 8,435 miles per $^1/_{32}$ inch wear and the following properties :

Chemical analysis.

Carbon	0·53 per cent.	Chromium	1·069 per cent.
Manganese	0·61 —	Vanadium	0·176 —

Physical test.

Elastic limit, lb. per square inch	140,325	Ratio	84·3 per cent.
		Elongation	12 —
Tensile strength, lb. per square inch	166,420	Reduction of area . . .	30 —

The ordinary carbon tires on similar wheels in the same service have shown a mileage of 5,237·2 per $^1/_{32}$ inch wear.

The use of special steels properly heat treated after being rolled into locomotive tires are now undergoing test in different parts of the country, but in no case have the tires been in service long enough to report the average wear per thousand miles.

Locomotive frames.

Frames for locomotives, wheel centers and ether castings. With the exception of the frames, the companies reporting have made no experiments with

special cast steel of high capacity and only three companies report experiments with frames, which in each case are with chrome-vanadium steel of the following average composition :

Chemical.

Carbon	0·32 per cent.	Sulphur	0·04 per cent.
Manganese	0·59 —	Vanadium	0·025 —
Phosphorous	0·042 —	Chromium	0·015 —
Silicon	0·286 —		

Nota. — Average tensile strength per square inch = 85,000 lb.

One Company reports two engines, one Company one engine, and one Company forty engines having chrome-vanadium steel frames, none of the frames have been in service more than a year and no failures have occurred.

It will no doubt be interesting to consider a lot of vanadium frames made for twenty-nine engines last summer, and, while some of the heats did not run as high as 85,337 pounds tensile per square inch, the performance of the steel under test was remarkable. The following analyses cover 40 per cent of the heats :

Chemical.

Carbon	0·27 per cent.	Sulphur	0·035 per cent.
Manganese	0·615 —	Silicon	0·28 —
Phosphorous	0·045 —	Vanadium	0·18 —

Physical per square inch.

Elastic limit, lb. per square inch	49,400	Elongation in 2 inches	26 per cent.
Tensile strength, lb. per sq. inch	86,200	Reduction of area	42·6 —

Owing to a shop error, three of these frames were discarded and broken up, a 5,000 pound weight or tup being used falling 18 feet. The frames being placed across iron supports about 4 feet apart. As high as twenty blows were gives without fracturing a double rail and, in no case, was a single rail fractured with less than six blows.

The average nomber of blows of the 5,000 pound weight falling 18 feet required to fracture each rail in the different sections was eight. For comparison an ordinary carbon steel frame was tested at the same time, and in no instance were more than two blows required to fracture any one section, all of the larger sections breaking under one blow.

The figure 1 shows one of the frames after being struck twenty blows from a height of 18 feet.

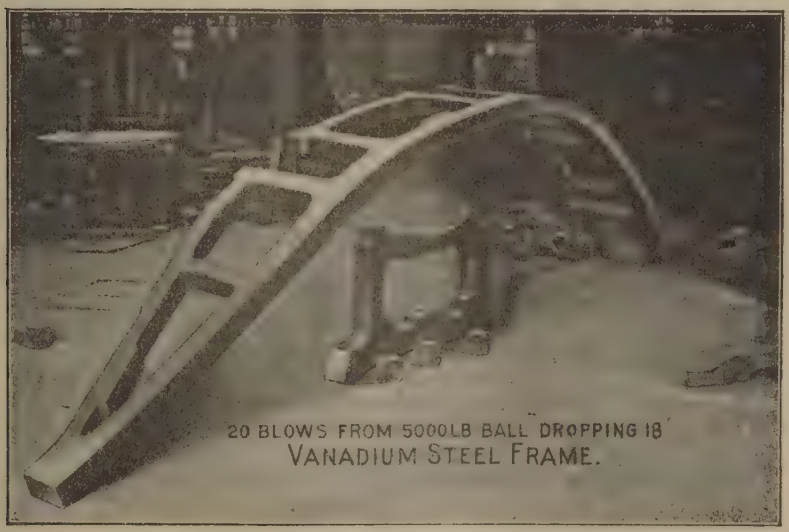


Fig. 1.

For piston rods and crank pins we have a number of reports of experiments started but no data on which to make comparison or give results as the experiments with special steels of 85,000 pound tensile strength per square inch, have been started during the past year and not carried far enough to draw conclusions.

It is to be regretted that the numerous tests now being made with heat treated alloy steels for axles, tires, springs, piston rods and crank pins have not been carried on a sufficient length of time to enable a conclusive comparative report being submitted.

I am indebted to and wish to thank the companies replying to my circular of inquiry, which consist of forty-five Railroad Systems in the United States, one in Canada, one in Mexico, and two in South America.

[621 .131.2 & 625 .246]

REPORT N° 3

(countries belonging to the " Verein Deutscher Eisenbahn-Verwaltungen ")

By Otto HÖNIGSBERG,

ENGINEER OF THE AUSTRIAN SOUTHERN RAILWAY COMPANY.

I. — Introduction.

Of the thirty-five railways having a total system of 95,757 kilometres (59,502 miles), which come within the scope of this report, fourteen administrations, with a system of 77,445 kilometres (48,060 miles), have answered the list of questions, two administrations have given particulars of the kinds of steel used by them and three other administrations have stated that they are not in a position to answer the list of questions.

The list of questions, both as regards arrangement and contents of the individual questions, was the same as that drawn up by Mr. Le Blant for the other countries of continental Europe; but the actual questions themselves were adapted to the special conditions of the countries which are the subject of this report.

The answers received accordingly apply, in accordance with the wording selected in the German list of questions, to " *Besondere Stahlgattungen von höherer Festigkeit* " (special kinds of steel of higher resistance), and also to those kinds of steel, which cannot be considered special steels in the narrower metallurgical meaning of the words (1), but which show a higher resistance, or special properties in connexion with the resistance. In agreement with the other reporters the answers received were

(1) The term special steel, alloy steel, is very generally applied to steel, which « owes its chief properties to the presence of one or more elements besides carbon » (Howe and Sauveur, *Report on the uniform nomenclature of iron and steel*, submitted to the fifth congress of the International Association for testing materials, Copenhagen, 1909).

treated on the uniform basis that the report should include, besides those kinds of steel which are special steels in the strict meaning of the term, also those kinds of steel which have a minimum ultimate tensile strength of more than 60 kilograms per square millimetre (85,336 lb. per square inch); which limit however received no application in the case of spring steel, which always has a greater strength.

The answers received apply to crank and to straight axles, to wheel tires, to springs and to other details mentioned in the last section of the list of questions.

Draft and buffing gear details are mentioned in the answers of one administration only, as made of basic Martin ingot iron (mild steel) having a minimum tensile strength of 40 kilograms per square millimetre (56,890 lb. per square inch) and a minimum elongation of 20 per cent; but according to the opinion of the reporter this does not fall within the scope of this report, and it is also not within the limit of 60 kilograms per square millimetre (85,336 lb. per square inch) specified above. The use of special steels of higher resistance for the details of draft and buffing gear will probably only become of importance, possibly in a very near future, when these parts will be strengthened to resist dynamic action.

Plate is also only mentioned in the answers of one administration, which is using since 1890 ingot iron having an ultimate tensile strength of 45 kilograms per square millimetre (64,000 lb. per square inch), an elongation of 25 per cent and a contraction of area of 40 per cent for boiler barrel rings, and ingot iron having an ultimate tensile strength of 40 kilograms per square millimetre (56,890 lb. per square inch), an elongation of 28 per cent and a contraction of area of 45 per cent, for flanged boiler plates; these materials accordingly also do not fall within the scope of this report. The trials begun some time ago, by a few administrations, of nickel-steel fireboxes, thus do not appear to have been continued, although it has more recently been recognized that the quick destruction of fireboxes is chiefly caused by heat stresses, and that this destructive action increases with the thickness of the plates. This should have drawn attention not only to the use of more elastic forms, but also to the reduction of the thickness of the plate, and especially to those kinds of nickel steel which according to Guilleaume's investigations do not expand at all, or only very little, when heated.

The names of the steel works manufacturing the kinds of steel in question are replaced by the arbitrarily-selected letters A, B, C..., but in such a way that the same letter is always used for the same works.

In designating the different types of locomotives according to their axles, the new system adopted by the German *Verein* is used (1), according to which the number of carrying axles is represented by Arabic numerals and the number of coupled axles by capital latters (one by A, two by B, three by C, etc.), the designations starting from the front of the locomotive and running from left to right.

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(1) See *Bulletin of the Railway Congress*, May 1909, p. 408 to 411.

II. — Crank axles.

The Baden State Railway uses nickel-steel axles for the four-cylinder compound express locomotives class II *d* (type 2 D 1, third axle driving axle), the four-cylinder compound superheated-steam express locomotives class IV *f* (type 2 C 1, fourth axle driving axle) and the four-cylinder compound superheated-steam goods locomotives class VIII *e* (type 1 D, fourth axle driving axle), that is for 34 per cent of all the crank axles. Crucible-steel axles are used for the twin express locomotives class II *c* (type 2 B, third axle driving axle) and the four-cylinder compound express locomotives class IV *e* (type 2 C, third axle driving axle), but at renewals nickel-steel axles are substituted for them. The axles now have 60 millimetre (1 3/8 inch) holes drilled in; the holes at both ends are closed by plugs which are pressed in and then centered.

The specified minimum values for axles are :

—	Nickel steel.	Crucible steel.
Ultimate tensile strength, in kilograms per square millimetre . . .	60	60
Elongation, measured on a length of 200 millimetres, per cent. . .	18	20
Contraction of area, per cent.	45	35
Tensile strength plus contraction	110	100

Test pieces are cut from both ends in the outside fourth of radius, also, if possible from the centre part and from one of the crank pieces; the results of the latter tests are however not binding. No impact tests are made.

Axles of nickel steel which show fractures, cracks or other defects connected with the material or its manufacture, before they have run 400,000 kilometres (248,550 miles), must be replaced by the manufacturer free of charge; but this guarantee expires in every case after six years in the case of express and passenger locomotives and after eight years in that of goods locomotives. Regular examinations of these axles are prescribed; particulars are given in the appendix. Fractures have as yet only occurred in the case of older crucible-steel axles with so-called crank-disks (table A) and are attributed to the less favourable distribution of the elastic strains in this design. Since 1902, the axles are only made with oblique webs, and of nickel steel; no signs of fracture have yet been found in any of these axles.

The wear of the journals (table C) is also considered to depend more on the design of the locomotive than on the material used, as the four-cylinder locomotives show materially less wear than the twin locomotives, while the crucible-steel and the nickel-steel axles of the four-cylinder locomotives class IV *e* show about the same wear.

Table A.

Index number.	Type and class of locomotive.	Total number of crank axles, and mean distance run per axle up to 1 January 1909.	Year of acquisition.	Cracks started: after running a distance of (kilometres)	Replacement on account of wear of journals became necessary: after running a distance of (kilometres)	Percentage: of cracks which have occoured.	Percentage: of axles replaced on account of wear.	Material of which the axles are made.	Notes as to the arrangement of the engines.
1	2 B twin express locomotive, class II*c*.	40 axles. 613,000 kilometres.	1893 to 1900.	237,544 111,175 361,195 740,336 726,498 on the average after 435,350	860,129 556,928 1,016,642 856,614 ... on the average after 820,000	12·5	10	Crucible steel	Inside cylinders; twin; the driving axle is next to the bogie.
2	2 C four-cylinder compound express locomotive, class IV*e*.	86 axles. 550,000 kilometres.	1894 to 1900.	324,298 554,369 409,500 656,875 543,536 609,621 on the average after 468,200	None as yet.	7	...	Crucible steel	The inside low-pressure cylinders attack the axle next to the bogie; the high-pressure cylinders are outside and attack the middle coupled axle (de Glehn's modification).
3	2 B 1 four-cylinder compound-express locomotive, class II*d*.	20 axles. 463,000 kilometres.	1902 and 1905.	None	None as yet.	...	...	Nickel steel.	High-pressure (inside) and low-pressure (outside) cylinders both attack the axle next to the bogie.

Table B.

List of the nickel-steel crank axles which have already run a considerable distance.

Class of locomotive.	Number of axles.	Distance run up to 1 January 1909. Maximum.	Distance run up to 1 January 1909. Mean.	Year of acquisition.	*Remarks.*
IIc	1	230,000	...	1902	Substituted for broken crucible-steel axles.
IVe	2	287,000 150,000	...	1902 1905	
IVe	2	635,000 589,000	...	1895	
IId Serie 1 . . .	13	692,000	570,000	1902	
IId Serie 2. . . .	7	354,000	285,000	1905	

Table C.

Index number	Class of locomotive.	Number of axles.	Mean wear of journals. Reduction of diameter by wear and truing up per 1,000,000 kilometres run. Bearing journal. left.	Bearing journal. right.	Crank journal. left.	Crank journal. right.	Material.	Mean distance run per axle up to 1 January 1909.	Year of acquisition.
1	IIc. . . .	40	8·6	12·5	17·7	19·2	Crucible steel.	613,000	1893 to 1900
2	IVe. . . .	86	0·98	1·08	6·15	5·15	...	550,000	1894 to 1900
3	IId. . . .	20	0·624	0·624	2·89	2·35	Nickel steel.	463,000	1902 and 1905
4	IVe. . . .	2	1·19 (1)	1·10 (1)	5·8 (1)	5·06 (1)	...	612,000	1895

(1) The figures for the wear of two nickel-steel axles of locomotives class IVe do not represent mean values, as there are only two axles. The same or similar figures for the wear are also found with a number of the 86 crucible-steel axles. All that can therefore be concluded from the comparison of these values with the others, as far as present experience goes, is that the wear of the two nickel-steel axles does not differ from the average of the crucible-steel axles.

The Bavarian State Railway uses on 109 four-cylinder compound locomotives of the types 2 B 1, 2 C, 2 B 2 (third axle driving axle) and 2 C 1 (fourth axle driving axle) cranked axles with oblique middle arm, made of 5 per cent nickel steel; on 42 locomotives crucible-steel crank axles are used.

Specified values for axles of

—	Nickel steel.	Crucible steel.
Ultimate tensile steel strength, in kilograms per square millimetre .	55 to 65	55 to 60
Contraction of area, per cent, at least.	40	40
Tensile strength plus contraction, at least	...	100

In the case of nickel-steel axles, every piece is tested.

As yet no nickel-steel axles have had to be replaced and they will also be used in the future for four-cylinder compound locomotives.

The Prussian State Railway uses for the crank axles (with straight arms) of its four-cylinder compound locomotives only 5 per cent nickel steel having an ultimate tensile strength of at least 60 kilograms per square millimetre (85,336 lb. per square inch), an elongation of at least 18 per cent (measured on a length of $11{\cdot}3\sqrt{F}$) and a contraction of area of at least 45 per cent. As yet no axle has had to be taken out on account of inferior quality of material or of work. This application will be continued.

The Alsace-Lorraine State Railway specifies for crank axles generally (for four-cylinder compound locomotives, de Glehn system, for express and passenger locomotives) nickel steel containing 5 to 7 per cent of nickel having an ultimate tensile strength of at least 60 kilograms per square millimetre (85,336 lb. per square inch), an elongation of at least 18 per cent and a contraction of area of at least 45 per cent. These axles have cranks of rectangular section, not drilled through; as yet no cracks have appeared, nor have any of these axles had to be taken out for any unusual reason; they are specially praised for the good wear of the surfaces of the crank journals.

The Saxon State Railway has since 1900 been using, for the crank axles of four-cylinder express locomotives, nickel steel containing 3 to 5 per cent of nickel, and having an ultimate tensile strength of at least 55 kilograms per square millimetre (78,225 lb. per square inch) and an elongation of at least 18 per cent; good results have been obtained and this application will be continued.

The Wurtemberg State Railway uses for its 2 C four cylinder compound express locomotives, de Glehn system, crank axles with oblique webs (Grafenstaden type), not drilled through, made of nickel steel.

—	Specification.		Results of tests.		
			Lowest.	Mean.	Highest.
Ultimate tensile strength, in kilograms per square millimetre	At least.	60	(62·7)	66·4	(70·7)
Elongation, per cent		18	(18·0)	20·6	(23·1)
Contraction of area, per cent		45	(47·6)	55·7	(60·0)
Tensile strength plus contraction, at least		110	(112·4)	122·1	(127·2)

The test pieces are cut cold out of the pieces obtained when cutting out the cranks.

Of the fourteen axles which have been in use since 1898, 1899, 1902 and 1905, none has as yet been taken out. The mean distance run by the axles which began running in 1898-1899, had reached 652,927 kilometres (405,717 miles) by the end of 1908, The new $^3/_6$ coupled four-cylinder compound superheated-steam locomotives are all equipped with nickel-steel crank axles, drilled through. Nickel steel is also to be used for the $^5/_5$ coupled three-cylinder compound goods locomotives of the Klose type, when any of the crank axles have to be renewed.

The Aussig-Teplitz Railway has one nickel-steel crank axle in use, on a 1 C three-cylinder compound passenger locomotive.

The Austrian State Railway uses for its four-cylinder compound locomotives (express locomotives of the 2 B 1 and 1 C 1 types, and superheated-steam locomotives for its undulating lines, of the 1 E type) crank axles, with hole drilled through, and with oblique webs, made of special Martin steel; some of these are forged out of one piece, others are composed of three pieces.

—	Specification.	Results of tests		
		Lowest.	Mean.	Highest.
Ultimate tensile strength, in kilograms per square millimetre	50-55, 55-60, 60-65	(56·6	60·8	(65·0
Elongation, per cent, measured on a length of $11{\cdot}3\sqrt{F}$, at least	At least 17, 16, 15	(16·0)	20·1	(23·5)
Contraction of area	... ...	(40·0)	54·4	(62·5)

The test pieces are cut from the axles, which are forged of greater length for the purpose.

The Austrian Southern Railway has since 1901 been using crank axles with

straight webs and centre bearing, made of 1 per cent nickel steel, on its two-cylinder compound locomotives of the type 2 C (third axle driving axle); it has since 1903 been using crank axles of refined steel (basic Martin steel, refined in a Martin furnace with acid lining) with oblique middle arm, on its four-cylinder compound locomotives of the 2 B 1 (third axle driving axle), 1 C 1 (third axle driving axle), and 1 E (fourth axle driving axle) types. Recently it has also been using axles of the same shape, made of special Martin steel and of crucible steel; these are all drilled, the most recent ones to 50 millimetres (1 $^{31}/_{32}$ inches).

—	Specification.	1 per cent nickel steel, works G.		Refined steel, works D.		Special Martin steel, works G.			Crucible steel, works G.		
		Mean.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Highest.	Lowest.	Mean.	Highest.
Ultimate tensile strength, in kilograms per square millimetre.	50-55, 55-60, 60-65	63·7	(58·7)	60·7	(63·1)	(55·4)	59·2	(65·0)	(58·6)	60·1	(62 4)
Elongation, per cent, measured on a length of $\sqrt{80\,F.}$	At least. 17 16 15	17·0	(18·5)	19·4	(20·5)	(20·0)	22·7	(24·4)	(19·0)	20·8	(23·0)
Contraction of area, in per cent.	... ...	53·7	(41·9)	47·7	(52·8)	(53·4)	57·0	(61·9)	(40·9)	45·1	(48·9)
Yield point, in kilograms per square millimetre.	... ...	...	...	...	...	...	...	...	(32·7)	35·1	(36·9)

Chemical composition :

Specification :	*Analysis of refined steel :*
Phosphorus content to be less than 0.04 per cent . . .	C = 0·31, Mn = 0·94, Si = 0·28, Ni = 0.39, Cu = 0.04, P = 0·03, S = 0·02.

Test pieces are to be cut from one axle of each heat, forged of greater length for the purpose.

A bar 400 millimetres (1 ft. 3 $^{3}/_{4}$ in.) long and having a diameter of 40 millimetres (1 $^{9}/_{16}$ inches) is notched in the middle by a sharp chisel which receives a blow of 25 kilogrammetres (180·8 foot-pounds); it is then placed on two supports 300 millimetres (11 $^{13}/_{16}$ inches) apart, with the notch underneath. It must then be able to stand three blows each of 50 kilogrammetres (361·6 foot pounds) without breaking. Nickel steel stood up to 43 blows before it broke.

Up till now one refined-steel axle of a four-cylinder compound express locomotive of type 2 B 1 had to be taken out, after running 520,000 kilometres (323,120 miles), because it broke at the neck-journal bearing of the high-pressure connecting rod.

The Hungarian State Railway uses for its four-cylinder and two-cylinder express locomotives nickel-steel axles with the pin drilled through.

A test piece 400 millimetres (1 ft. 3 3/4 in.) long and having a diameter of 40 millimetres (1 9/16 inches) is notched in the middle by a sharp chisel having a cutting angle of 75 to 85° which receives a blow of 25 kilogrammetres (180·8 foot-pounds), the test piece being supported on a piece of wood; it is then placed on two iron supports 300 millimetres (11 13/16 inches) apart, with the notch underneath. It must then be able to stand three blows each of 50 kilogrammetres (361·6 foot-pounds) without breaking.

Up till now no axle has had to be taken out

The Dutch Railway Company has 272 crank axles (straight webs, centre bearing, and wrought-iron rings shrunk on) in use on its two, three, four and five axle twin locomotives; 110 of these are made of nickel steel, for which there is no special specification. The fractures and cracks which have hitherto been observed have not enabled any definite conclusions to be drawn as to their cause. Up till now 6 of the nickel-steel axles have been taken out in consequence of transverse cracks. Owing to the short time the nickel-steel axles have been in use as compared with the others, no definite figures can be given as to comparative merit; but the results obtained with nickel-steel axles are considered very satisfactory and when new locomotives are now ordered only nickel steel is specified.

The Dutch State Railway uses nickel steel, crucible steel and special Martin steel for the 1 B, the 2 B and the 2 B 1 twin locomotives.

—	Nickel steel.	Crucible steel.	Special Martin steel.
Ultimate tensile strength, in kilograms per square millimetre, at least.	60	55	55
Limit of elasticity, in kilograms per square millimetre, at least. . .	40	32	30
Elongation, per cent, measured on a length of 200 millimetres, at least	18	20	20
Contraction of area, per cent, at least	40	45	50
Tensile strength plus elongation, at least	80	78	78

At least two tensile tests are made on each axle which must be forged of greater length for the purpose. No drop test is prescribed, but on the other hand two cold bending tests are made on each axle; bars of square section, 30 × 30 millimetres (1 3/16 × 1 3/16 inches), are used which are doubled up until the surfaces are in contact. No cracks may appear.

Fractures and cracks have led to some of the axles being taken out; accurate comparative figures are not available.

The Roumanian State Railway specifies that crank axles shall be made of nickel steel.

SUMMARY.

Nickel steel is used very extensively for crank axles, particularly when renewals or new locomotives are in question; this steel contains from 1 to 7 per cent of nickel, 5 per cent being most usual. A number of German railway administrations agree in specifying that this material is to have a minimum tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch), a minimum elongation of 18 per cent and a minimum contraction of area of 45 per cent. It is generally intended to continue its use, and in some cases to extend it. Good results have however also been obtained by some administrations with other kinds of steel, such as crucible steel. Drilling holes in order to detect any piping is becoming more and more usual. Specifications as to manufacture are as a rule not made (except the clause, very usual with the Austrian railways, that the cooling is to be slow), and this applies equally to all kinds of steel. No particulars are given as to the process of manufacture at the steel works.

Test pieces are cut partly from axles forged of greater length, partly from the pieces cut out of the cranks; the pieces, in so far as any specifications exist, are to be worked cold. The Baden State Railway, besides test pieces cut from the outer fourth of the radius at the two ends, also makes tests of the pieces cut out at the cranks and bored out, but these are not considered binding. Differences according to kind of metal are not made in this respect. The Bavarian State Railway requires tests to be made of each axle in the case of nickel steel.

There are as a rule no special specifications as regards impact tests; in many cases no impact tests are required. Several Austrian and Hungarian railways specify a special kind of impact test made on notched bars, cut from a part of the axle forged of extra length, the notch being produced by a blow of a chisel. Some administrations limit this to nickel-steel axles.

As regards fractures and cracks, and the life of the axles generally, the consistent results obtained, especially the careful observations made by the Baden State Railway, show that besides the design of the locomotives, the shape of the axles is also a factor of much importance. There is no doubt that axles without centre bearing and with oblique middle arm have given good results, and are used more and more; the gradually-developed shape forms an approach to that of uniform strength (1). The Baden State Railway, in the case of nickel-steel axles, requires a guarantee of a minimum life of 400,000 kilometres (248,550 miles).

The Austrian State Railway has recently been using axles of this kind, which are made up of three parts, so that during the forging operations the middle arm has more work put on to it (2).

(1) Compare the shapes of cranks according to Klose (German patent No. 143574, of 1902) and Frémont (*Revue de Métallurgie*, 1904), which reduce the risk of fracture, by the removal of useless material; also the continued use of axles in which cracks have started, after putting in Frémont biscuit-shaped openings in the crank disks (*Revue générale des chemins de fer*, 1908).

(2) Compare with this : *Glasers Annalen*, 1910, p. 51.

III. — Straight axles.

The Baden State Railway used up to 1907 only Martin or crucible steel having a minimum ultimate tensile strength of 50 kilograms per square millimetre (71,114 lb. per square inch), a minimum elongation of 18 per cent (measured on a length of 200 millimetres [7 7/8 inches]) and a minimum contraction of area of 40 per cent, and tensile strength added to contraction had to be at least 95. The driving, coupled and carrying axles of the newest locomotives IV *f* and VIII *e* (compare crank axles) and to the tank locomotives class X *b* (arrangement of axles, D), forming together 7·25 per cent of the total locomotive stock, now are of crucible steel having a minimum ultimate tensile strength of 50 kilograms per square millimetre (71,114 lb. per square inch), a minimum elongation of 20 per cent, and a minimum contraction of area of 35 per cent; strength added to contraction must give at least 100. As an experiment tender axles are made of nickel steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch), a minimum elongation of 18 per cent and a contraction of area of 45 per cent, and strength added to contraction must give at least 110. The crucible-steel axles mentioned are bored out to a diameter of 50 and 60 millimetres (1 31/32 and 2 3/8 inches); the holes are closed at the ends by plugs driven in, which are then centered.

Impact tests are made, without distinction of metal, on axles placed on supports 1·50 metres (4 ft. 11 in.) apart; the tup weighs 600 kilograms (1,320 lb.) and the axle is turned after each blow. Two blows are given with a drop of 5 metres (16 ft. 5 in.), two with one of 5·5 metres (18 feet), one with one of 6 metres (19 ft. 8 in.) and one with one of 6·5 metres (21 ft. 4 in.); if the sum of the deflections is not yet equal to 280 millimetres (11 inches), further blows are given with a drop of 5 metres (16 ft. 5 in.); if the tup has a different weight, the heights of drop are adjusted so that the blows given have the same force.

Up to 2 per cent of the axles are tested. With hollow axles as well as with crank axles, no impact tests are made.

A guarantee of two years is required, without distinction of material.

Fractures and cracks have as yet not been observed; owing to the short period of use, no definite results have yet been obtained; but crucible steel having an ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch) will in the future be specified in the case of locomotives with high axle-loads. Results of the trial of nickel-steel tender axles are not yet available.

The Bavarian State Railway uses for the driving axles of seven main-line automotor cars (axle arrangement B, both coupled axles being driving axles) and for the carrying axles of twelve main-line passenger locomotives type 1 B, axles of 5 per cent nickel steel; for eighty-seven other locomotives of the same class crucible steel is normally used.

—	Specification for		
	Martin or Bessemer steel.	Nickel steel.	Crucible steel.
Ultimate tensile strength, in kilograms per square millimetre	50 to 55	55 to 60	55 to 60
Contraction of area, per cent, at least	...	40	...
Tensile strength plus contraction, at least	95		100

Impact tests are not specified. One axle is tested out of each second heat, in the case of nickel steel out of each heat. Guarantee, three years for all kinds of steel. No straight axles of nickel steel have yet been taken out; nickel-steel axles are not going to be supplied in the future to the locomotives named above.

The Aussig-Teplitz Railway uses crucible steel and 3 per cent nickel steel for the driving and coupled axles of locomotives (on 8·6 per cent of all the locomotives), and for the axles of six-wheeled braked tenders (on 30 per cent of all the tender axles).

—	Specification for		Results of tests on steel containing 3 per cent of nickel.		
	Wagons and tender axles.	Locomotives axles.			
Ultimate tensile strength, in kilograms per square millimetre	Minimum. 50	50 to 65	(55·2)	55·7	(56·2)
Elongation, per cent	...	...	(19·0)	20·4	(21·8)
Contraction of area, per cent	Minimum 35		(43·2)	46·3	(49·3)

With wagon and tender axles, one impact test and two tensile tests of the adjoining part are made : in the case of Martin, refined or special steel, of each second heat; in the case of crucible steel, of one axle out of every fifty axles, or fraction of fifty. The tests are carried out as on the Austrian State Railway (see below). In the case of locomotive axles, one tensile test is made of each heat; these axles are all forged of extra length for the purpose.

Guarantee for axles of Martin, refined or special steel, three years; for axles of crucible steel, four years.

Within twenty years the following fractures have occurred :

Locomotive axles : two of crucible steel, one of them after running 446,000 kilometres (277,140 miles), in consequence of a flaw in the material; no other axle has broken.

Tender axles: one of crucible steel after running 628,000 kilometres (390,230 miles), in consequence of a sharp corner at the inner side of the wheel centre; fourteen of other steel.

The Austrian State Railway uses axles made of steel containing 3 per cent and 1 per cent of nickel, and of special Martin steel, with holes 30 millimetres (1 3/16 inches) in diameter, for the driving, coupled and carrying axles of locomotives, also for tenders in current use.

—	Specification for :		
	Tender and wagon axles of special or crucible steel, locomotive axles of Martin, special or crucible steel.	Locomotive and tender axles of steel containing 1 per cent and 3 per cent of nickel.	Results of tests of steel containing 1 per cent of nickel.
Ultimate tensile strength, in kilograms per square millimetre	50-55, 55-50, 60-65	55-60, 60-65	(55·7) 61·5 (69·1)†
	At least	At least	
Elongation, per cent, measured on a length of $11{\cdot}3\sqrt{F}$	17 16 15	16 15	(16·0) 18·1 (21·0)
Contraction of area, in per cent	...	...	(38·7) 51·7 (62·4)

Impact tests on tender and wagon axles, placed on supports 1·5 metres (4 ft. 11 in.) apart; blows having a force of 3,000 kilogrammetres (21,700 foot-pounds) are given until the deflection, measured from a chord 1·5 metres (4 ft. 11 in.) long, amounts to 200 millimetres (7 7/8 inches); the force of the last blow must be adjusted so that this deflection is not materially exceeded; the axle is then turned through an angle of 180° and blows of the same force are applied until the axle is straightened again.

With wagon and tender axles, one impact test and two tensile tests of the adjoining part are made of each second heat, or at least of one axle out of every fifty axles, or fraction of fifty. With locomotive axles one tensile test is made of each heat; three axles of each heat must be forged of extra length for the purpose.

With nickel-steel axles, impact bending tests are made with notched bars from the cut-off ends of the axles forged of extra length. The test bar is 400 millimetres (1 ft. 3 3/4 in.) long and turned down to a diameter of 40 millimetres (1 9/16 inches); it is placed on two supports rounded to a radius of 10 millimetres (3/8 inch), which are 300 millimetres (11 13/16 inches) apart. It is then supported at the centre, and notched with a chisel having a cutting edge of 45°, to which a blow of 25 kilogrammetres (180·8 foot-pounds) is applied. The centre support is then removed, the bar is turned over so that the notch is underneath, and blows having a force of 50 kilogrammetres (361·6 foot-pounds) are then applied. Fracture must not take place before three blows in the case of steel containing 1 per cent of nickel or before five blows in that of steel containing 3 per cent of nickel.

The Austrian Southern Railway has since 1904 been using special Martin steel

for new locomotive axles and also for some of the tender axles. As an experiment the following were used also : 1 per cent nickel steel for the coupled and carrying axles (besides the driving axles) of four 2 C two-cylinder compound express locomotives, for the axles of 2 B local-train tank locomotives, and for all the axles of one 1 C two-cylinder compound goods locomotive; 5 per cent nickel steel for the driving axles of three C and two D goods locomotives, in which cracks were often found. The new locomotive axles have holes with a diameter of 30 millimetres ($1\ ^3/_{16}$ inches), and in some cases of 40 millimetres ($1\ ^9/_{16}$ inches), drilled in.

—	Specification.	Results of tests.			
		Special Martin steel. Works F.	Special Martin steel. Works G.	Nickel steel 1 per cent. Works G.	Nickel steel 5 per cent. Works G.
Ultimate tensile strength, in kilograms per square millimetre.	50 to 55 55 to 60 60 to 65	(50·9) 58·3 (60·2)	(57·1) 62·0 (67·2)	59·5	63·2
Elongation, per cent, measured on a length of $\sqrt{80\ F}$.	At least 17, 16, 15	(22·0) 23·3 (24·5)	(15·0) 18·9 (21·9)	15·2	21·7
Contraction of area, per cent.	...	(56·0) 59·6 (62·0)	(41·1) 48·3 (56·7)	37·3	61·8
Yield point, in kilograms per square millimetre.	...	...	...	...	46·3

CHEMICAL COMPOSITION :

Specification :	*Analysis of 5 per cent nickel steel.*
Phosphorus content to be less than 0·04 per cent . . .	C = 0.254, Mn = 0.197, Ni = 4.911, Si = 0.168 P = 0.020, S = 0 09, Fe = 94.220

With tender and wagon axles, one impact test and one tensile test of the adjoining part, are made on one axle out of every 50 to 60 axles. The impact tests are made as on the Austrian State Railway, except that in the case of axles having a diameter exceeding 150 millimetres ($5\ ^{15}/_{16}$ inches) a deflection of only 165 millimetres ($6\ ^1/_2$ inches) is specified, and that deflection is measured from two centre-punch marks in the axle placed symmetrically 1,500 millimetres (4 ft. 11 in.) apart.

With locomotive axles, and when less than 50 axles are supplied, impact tests are made on notched bars as specified in the case of crank axles (see specification, given above, of the Austrian State Railway). Period of guarantee for all kinds of steel, three years.

No fractures nor cracks have yet been observed in the special-steel axles in use (at the end of 1908, about 12 per cent of the locomotive axles and 6 per cent of the

tender axles). Of the 3 per cent nickel-steel driving axles of D goods trains one had already to be taken out after running 64,000 kilometres (39,770 miles) owing to cracks at the end of the grooves of the two crank seats (Hall cranks).

The Hungarian State Railway uses 3 per cent nickel steel having an ultimate tensile strength of 55 to 65 kilograms per square millimetre (78,225 to 92,450 lb. per square inch) and a contraction of area of 40 per cent for the driving axles of express locomotives, and also in cases where the nature of the lines and smaller dimensions appear to make it necessary, namely for the driving, coupled and carrying axles of locomotives of class I *n*, and for the axles of Vanderbilt tenders.

Impact tests on notched bars are made as in the case of crank axles. One impact and one tensile test is made of each heat.

It is intended to extend this application to the driving and coupled axles of express locomotives.

The Prinz-Heinrich Railway is as an experiment using driving, coupled and carrying axles of locomotives (2 per cent of the total stock) made of special steel supplied by works B, having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch); there is no further specification and owing to the short time these have in use no results have as yet been obtained.

SUMMARY.

Straight axles made of special steel are used by some administrations, chiefly experimentally, for the driving, coupled and carrying axles of locomotives, and in some cases for the axles of tenders. The steels used are nickel steel containing 1 per cent, 3 per cent and 5 per cent of nickel, having a minimum ultimate tensile strength of 50 to 55 kilograms per square millimetre (71,114 to 78,225 lb. per square inch), an elongation of 17 to 18 per cent and a contraction of area of 35 to 40 per cent, except in the case of the Baden State Railway which specifies minimum ultimate tensile strengths of up to 60 kilograms per square millimetre (85,336 lb. per square inch, a minimum elongation of 18 per cent, a minimum contraction of area of 45 per cent, and also that tensile strength plus contraction must give at least 110, as with crank axles; some Austrian railway administrations specify 5 kilograms per square millimetre (7,110 lb. per square inch) more tensile strength in the case of special Martin steel, while specifying the same elongation as in the case of the ordinary Martin steel used for wagon axles. The Baden State Railway uses for its latest types of locomotives crucible steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch), a minimum elongation of 20 per cent, and a minimum contraction of area of 35 per cent, and also specifies that strength plus contraction must give at least 100. The Prinz-Heinrich Railway uses special steel having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch), but nothing else is specified. As regards the manufacture of the axles and the cutting

out of the test pieces the same rules apply as in the case of crank axles. Some of the administrations drill holes in order to detect any piping.

Impact tests are made in the same way as with axles made of other material; on the Austrian and Hungarian lines a special kind of impact test, on notched bars, is made in the same way as in the case of crank axles. Some of the administrations prescribe a greater number of tests in the case of crucible steel than in that of other kinds of steel. The Bavarian State Railway requires tests of each nickel-steel axle. The Aussig-Teplitz Railway specifies a longer period of guarantee for crucible steel (four years intead of three).

Concordant results about these kinds of steel are not available; the fractures and cracks recorded in this case also show the great influence of the design and of the working of the stock. But the administrations agree in considering that special kinds of steel should be used for new locomotives, which have to give greater speeds or greater tractive force.

IV. — **Wheel tires.**

The Baden State Railway uses crucible steel for 21 per cent of its locomotives, namely for all the wheels of the more recent express locomotives of classes II*c*, IV*e*, II*d* and IV*f*, of the goods locomotives class VIII*e* and the shunting locomotives class X*b*; it also uses Martin steel of higher resistance for the unbraked wheels of the older locomotives. The latter is also to be used experimentally for the braked wheels of locomotives and tenders.

—	Minimum values specified.		
	Crucible steel.	Acid or basic Martin steel	
		for unbraked wheels.	for braked wheels.
Ultimate tensile strength, in kilograms per square millimetre	70	60	50
Elongation, per cent, measured on a length of 200 millimetres	15	16	20
Contraction of area, per cent	25	25	35
Tensile strength plus contraction	100	90	90
Impact test	6 blows with a tup weighing 600 kilograms falling from a height of 5 metres (if a tup of different weight is used, the height must be adjusted so that a blow of the same force is given).		
Guarantee, years	5	2	2
Number tested	2 per cent. In each case one test piece from the middle and one from the inner or outer part of the cross-section.		

Results of comparative trials are not available. Crucible steel is going to be used in the future for locomotives which have much work to do or have heavy axle-loads.

The Bavarian State Railway uses basic Martin steel of higher resistance for all the tires of three 1 C street-railway tank locomotives with leading Bissel truck, running on a grooved-rail track having a gauge of 1 metre (3 ft. 3 ⅜ in.); it uses crucible steel for all the other locomotive tires.

—	Tender and wagon tires made of Martin or Bessemer steel.	Locomotive tires made of crucible steel.	Street-railway locomotive tires made of Martin steel.	
	Specified values.			Results of tests.
Ultimate tensile strength, in kilograms per square millimetre	60 to 68	65 to 73	At least. 80	80·1 to 90·9
Elongation, per cent	...	...	...	9·0 to 18·5
Contraction of area, per cent.	At least. 30	25	...	15·4 to 33·0
Tensile strength plus contraction	95		..	...
Guarantee, years	3	3	3	3
Number of tests	One out of each heat.			

The tires of these street-railway locomotives had to be trued the first time, owing to the great wear of the tires at the curves of the grooved rails, already after running 4,000 kilometres (2,485 miles); the flanges were trued flatter and the second time truing became necessary after 12,000 kilometres (7,455 miles). After 29,000 kilometres (18,020 miles) the tires on the driving and coupled wheels had to be replaced, the carrying-wheel tires not being changed. Fractures have not occurred in the two and a half years till now.

The Prussian State Railway uses in current practice locomotive and tender tires made of Martin steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch), and of crucible steel having one of 70 kilograms per square millimetre (99,560 lb. per square inch). Experimentally, locomotive tires have been made of "re-melted crucible steel" (remnants and broken pieces of crucible-steel tires melted together with those of Martin steel) having an ultimate tensile strength of 65 and 70 kilograms per square millimetre (92,450 and 99,560 lb. per square inch); of Martin steel having an ultimate tensile strength of 65 and 70 kilograms per square millimetre (92,450 and 99,560 lb. per square inch); of nickel steel with 1 to 2 per cent of nickel added, and of electro-steel.

*

Elongation and contraction of area are not specified; the impact tests serve as a measure for the toughness. Blows each of 3,000 kilogrammetres (21,700 foot-pounds) (weight of tup 1,000 kilograms [2,205 lb.], or if this is not practicable, 500 kilograms (1,102 lb.); the apparatus should be able to give blows of up to 5,600 kilogrammetres [40,500 foot-pounds], increased each time by 500 kilogrammetres (3,617 foot-pounds) if the deformation is less than 10 millimetres ($^3/_8$ inch). A deformation of 12 per cent must be attained with Martin steel, and with crucible steel one of

$$\left(\frac{D}{100} - \frac{d - 65}{10}\right) \text{ per cent,}$$

where D is the diameter of the rolling surface and d the thickness of the tire in its finished condition, both being given in millimetres. Two per cent of the tires are tested in the case of crucible steel, and four per cent in that of re-melted crucible steel.

It must be possible to force the tires on the wheels with a shrinkage allowance of 1 millimetre for every metre of internal diameter, without the tires showing any cracks or other defects which are due to the material or its process of manufacture.

The experimental application of the kinds of steel named above has only begun recently; the kilometre records have only just been begun. Their more extended application depends on their successful use and on the economic results obtained.

The Alsace-Lorraine Railway uses for locomotives having axle-loads of up to 16,000 kilograms (35,270 lb.), tires made of crucible steel having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch), as well as tires made of Martin steel having a minimum ultimate tensile strength of 50 kilograms per square millimetre (71,114 lb. per square inch).

The specification for the tests is the same as on the Prussian State Railway.

Trials were made with ten locomotives, one axle of each being fitted with crucible-steel tires and another with Martin-steel tires; after eight months it was found that the mean wear of the crucible-steel tires was 3 millimetres ($^1/_8$ inch) as compared with 4·5 ($^3/_{16}$ inch) in the case of Martin-steel tires. Crucible-steel tires have not yet shown any fractures or cracks. Attention is drawn to the fact that the axle-loads on carrying axles with wheels of small diameter must not be too high; or else the rolling surfaces show a tendency to become laminated.

In consequence of these experiments, all tires having a diameter of more than 1,500 millimetres (4 ft. 11 in.) are now made of crucible steel exclusively, that is on the average 300 tires per year as against 1,700 Martin-steel tires. It is not intended to extend this application any further (except as regards the carrying axles of passenger and express locomotives) as the Martin-steel tires, which are materially cheaper, perfectly satisfy all requirements as regards the safety of the traffic.

The Saxon State Railway has for some time been using for its locomotives crucible-steel tires having a minimum ultimate tensile strength of 65 kilograms per square

millimetre (92,450 lb. per square inch) and a minimum elongation of 10 per cent, with good results, and intends to continue to use them.

The Wurtemberg State Railway is about to try special steel supplied by works B for the tires of the driving and coupled axles of tank locomotives and goods locomotives; at the time the list of questions was answered these had not yet started running.

—	Specific minimum values.	Results of tests, mean.
Ultimate tensile strength, in kilograms per square millimetre	82	81·3
Elongation, in per cent	10	14·5
Contraction of area, in per cent	20	21·2
Reduction of diameter, per cent, after blows given by tup of 600 kilograms falling from a height of 5 metres.	12	12·8 after nine blows.

One test to every 50 tires, or fraction of 50 tires.

The Aussig-Teplitz Railway uses for 19·3 per cent of the locomotive axles and for 1·2 per cent of the passenger-carriage axles (in the case of braked axles also), tires made of crucible steel and special Martin steel having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch) and a minimum contraction of area of 25 per cent; for the others it uses basic Martin steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch) and a minimum contraction of ares of 35 per cent.

—	Specified minimum values for crucible steel and special steel.	Results of tests.	
		Crucible steel supplied by works F.	Special Martin steel supplied by works G.
Ultimate tensile strength, in kilograms per square millimetre	70	(71·1) 73·8 (76·7)	(73·1) 76·3 (78·2)
Elongation, per cent, measured on a length of $11.3\sqrt{F}$.	...	(10·0) 12·6 (16·0)	(13·5) 14·1 (14·5)
Contraction of area, per cent	25	(31·9) 37·8 (47·1)	(36·9) 39·5 (42·3)

Specified reduction of diameter (deformation) 12 per cent, produced by blows of 3,000 kilogrammetres (21,700 foot-pounds); crucible-steel tires and special Martin-steel tires require about twice as many blows for the purpose as Martin-steel tires of the same dimensions.

One test to every 50 or 60 tires, or fraction thereof.

Comparative trials made with 56 tires on goods locomotives class IV *b* (type D) during five years showed no differences worth mentioning between crucible steel and special Martin steel as regards wear; as compared with ordinary basic Martin steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre and a minimum contraction of area of 35 per cent, the distance run was 1·4 times as great. The first truing of the tires took place after 80,000 kilometres (49,710 miles); the flanges were also worn less than with ordinary basic Martin steel. During the last twenty years, two crucible-steel and five Martin steel locomotive tires have broken.

The Austrian North Western Railway (1) has special steel supplied by works A, having an ultimate tensile strength of 80 to 84 kilograms per square millimetre (113,780 to 119,470 lb. per square inch), an elongation of 16 to 14 per cent and a contraction of area of 36 per cent; this is in use in current practice for the tires of loco motive bogies and, as an experiment, for tender tires. As yet no special specification has been drawn up, and no impact tests have yet been made, owing to smallness of numbers. The distance run per millimetre of wear during five years of express service was on the average :

Locomotive bogies . . 12,800 kilometres (202,010 miles per inch), as against 13,800 kilometres (217,792 miles per inch) in the case of crucible steel.

Tenders . . . . . 13,194 kilometres (208,228 miles per inch).

The truing is made necessary by spots which have become worn, laminated, and flat.

The Austrian State Railway uses for locomotives and tenders of all kinds, and also for some carriages, tires made of crucible steel and of special Martin steel which according to the steel works is made of better-quality old metal (own scrap) melted in a Martin furnace, with a little chromium added.

—	Specification.			
	Basic Martin steel for		Crucible steel or special Martin steel for	
	Carriages.	Locomotives and tenders.	Carriages.	Locomotives and tenders.
Ultimate tensile strength, in kilograms per square millimetre.	50 at 65	65 at 75	65 at 80	70 at 85
Elongation, per cent, measured on a length of $11{\cdot}3\sqrt{F}$, at least.	14	10	10	10
Reduction of diameter produced by blows of 3,000 kilogram-metres each	12		9	$\frac{D}{100} - \frac{d-65}{10}$
Results of tests :	Crucible steel.		Special Martin steel.	
Ultimate tensile strength, in kilograms per square millimetre	(69·4) 75 (83·9)		(71·1) 77 (85)	
Elongation, per cent	(10·5) 13·5 (17·5)		(10·5) 14·5 (18·5)	
Contraction of area, per cent.	(26) 38 (53·1)		(29·5) 46·5 (61·1)	

(1) This line has now been incorporated in the system of the Austrian State Railway.

The material must have such toughness that when the tires are put in place with a shrinkage allowance of 1 millimetre per metre of internal diameter there is no appearance of a crack or other defect. One tire is tested out of every heat, or at least 2 per cent of the tires, or one tire out of each lot supplied; in the case of crucible-steel tires, one tire out of every 50 tires, or fraction thereof. In each case, one tensile test from the flange side and one tensile test from the opposite side.

The yield point is only determined for own information.

Ball-pressure tests are not specified.

Period of guarantee, four years.

According to present experience, tires of crucible steel do not become worn as quickly as tires of special Martin steel.

The Austrian Southern Railway has since 1904 been using for all the wheels of the locomotives and of the tenders and of the carriages used for express and passenger trains, tires of special Martin steel, while formerly crucible steel and refined steel were used for these tires; all the other tires are made of basic Martin steel.

—	Specification.	
	Basic Martin steel.	Crucible steel, refined steel and special steel.
Ultimate tensile strength, in kilograms per square millimetre	50 at 65	65 at 75
Elongation, per cent, measured on a length of $\sqrt{80\,F}$.	At least. 18	At least. 15
Contraction of area, per cent	...	...
Yield point, in kilograms per square millimetre	...	...
Phosphorus content	less than 0·04 per cent.	

In addition, as an experiment, tires of harder steel :

—	Results of tests.	
	Special crucible steel supplied by works A.	Special Martin steel supplied by works G. Mean values.
Ultimate tensile strength, in kilograms per square millimetre	(81·6) 82·9 (83·6)	84·3
Elongation, per cent (Measured on a length of)	(15·4) 15·9 (17·2) ($\sqrt{80\,F}$)	9·3 ($11·3\sqrt{F}$)
Contraction of area, per cent	(34·0) 36 7 (39·2)	22·1
Yield point, in kilograms per square millimetre.	(46·0) 49·2 (52·8)	...

specially in the case of the second material for the carrying wheels of a 1 C 1 two-cylinder compound passenger tank locomotive, having a diameter of 840 millimetres (2 ft. 9 1/16 in.) and an axle-load of 14 tons.

Specified reduction of diameter by blows of 3,000 kilogrammetres (21,700 foot-pounds) each : Martin steel, 12 per cent; special steel, crucible steel and refined steel, 9 per cent. With the special crucible steel named above, 13 per cent was attained after 12 blows totalling 77,000 kilogrammetres (556,950 foot-pounds). One tire is tested out of every 50 to 60 tires. Period of guarantee, four years.

An investigation of the distances run during the last eleven years by the tires of 96 goods locomotives of the D type *i. e.*, up to the end of the year 1908, the trailing axle having lateral play, and running in undulating country, was made, and the distance run per millimetre of wear determined. The following results were obtained :

SECTION OF LINE.	Steepest gradient, per mil.	Radius of sharpest curve, in metres.	Crucible steel, works A.	Special steel, works B.	Crucible steel, works B.	Special Martin steel, works F.	Crucible steel, works F.
a) (1)	25	237	5,500	4,800	5,600	3,900	4,200
b)	25	190	7,700	...	7,100	7,700	5,200
c)	25 (2)	250	9,900	11,200	10,900	7,900	9,400
d)	13·7 (2)	272	12,600	9,700	11,700	10,100	11,400
Mean	...	...	8,900	8,200	8,800	7,400	7,550
Number of tires . .	...	...	52	32	116	406	202

(1) Very unfavourable climatic conditions.
(2) Only on a short section.

About 31 per cent of the tires used on locomotives and tenders at the end of 1908, and 15 per cent of those used on passenger carriages, were of special Martin steel. In the case of the locomotive and tender tires, flats and exfoliations were observed, and lamination particularly in the case of small carrying wheels; there was only one case of fracture, that of a tender tire.

Their further use to the same extent is continued.

The Hungarian State Railway uses ordinary and hard crucible steel, and also special Martin steel (chrome steel), for the tires of driving and coupled wheels, also of carrying wheels of express locomotives and tenders class I *n*. (See the following table.)

One test is made of each heat.

The ball-hardness test is made in the usual way on cross-sections at least 35 millimetres (1 3/8 inches) thick with a ball 19 millimetres (3/4 inch) in diameter and a load

of 50,000 kilograms (110,230 lb.), and determined as quotient of the load in kilograms divided by the area of depression in square millimetres.

—	Martin steel.	Ordinary crucible steel.	Hard crucible steel.	Special steel (chrome steel).
Ultimate tensile strength, in kilograms per square millimetre	At least. 55	At least. 60	70-90	
Elongation, per cent	...	...	At least : 15-10 per cent.	
Force of blows, in kilogrammetres	3,000			
Number of blows	...			4
Reduction of diameter, per cent	At least. 12		...	
Ball-hardness test (not specified)	150	160	185	

No definite opinion can as yet be given as regards the behaviour of the tires made of special steel as they have only been a short time in use. They are about to be used in the case of locomotives running at high speed for the wheels of crank axles and for the wheels of the tenders.

The Dutch State Railway uses crucible steel and special Martin steel in current practice.

—	Locomotives and tenders.	Carriages.	Rolling stock of narrow-gauge lines.
Ultimate tensile strength, in kilograms per square millimetre	68 to 74	55	80 to 90
Elongation, per cent	16 to 14 measured on a length of 200 millimetres ($11{\cdot}3\sqrt{F}$).	18	10 to 8 (measured on a length of 100 millimetres).
Contraction of area, per cent	25	30	...
Limit of elasticity, in kilograms per square millimetre	40	30	45
Weight of tup, in kilograms	1,000	500	
Height of drop, in metres, for diameters	over 1,000 millim. 10 under or equal to 6	6	1. blow 3 2. blow 9 3. and 4. blow 6
Number of blows	4		
Specified reduction of diameter, per cent.	18	12	10

Two per cent of the tires are tested, or at least one tire out of every heat ; two tensile tests are made of each tire tested. No results of comparative trials are available.

The Prinz-Heinrich Railway uses special-steel tires with screw fastenings on sixteen locomotives and tenders; this steel has an ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch). Elongation, contraction of area and impact tests are not specified. Owing to the short period these tires are in use, no results have yet been obtained.

The Rumanian State Railway uses crucible steel for express locomotives, Martin steel having an ultimate tensile strength of 68 to 74 kilograms per square millimetre (96,715 to 105,250 lb. per square inch) for goods locomotives, and Martin steel having an ultimate tensile strength of 60 to 65 kilograms per square millimetre (85,336 to 92,450 lb. per square inch) for carriages.

SUMMARY.

Most of the railways use, for their more recent locomotives running at high speeds and giving great power, and their tenders, in some cases also for other locomotives and tenders and for passenger carriages, wheel tires having minimum ultimate tensile strengths of 60 to 70 kilograms per square millimetre (85,336 to 99,560 lb. per square inch), minimum elongations of 10 to 15 per cent and minimum contractions of area of 25 per cent. As a rule they use crucible steel and special Martin steel, in some cases specially-hard tires are used, made of special crucible steel having minimum ultimate tensile strengths of 80 to 82 kilograms per square millimetre (113,780 to 116,630 lb. per square inch), minimum elongations of 10 per cent and minimum contractions of area of 25 per cent; the tests made show elongations of up to 17 per cent (measured on a length of $\sqrt{80\,F}$) and contractions of area of up to 39 per cent. As regards the manufacture of wheel tires, the same applies as stated in the case of axles. The tires are nearly always fastened by means of rings. The tensile tests are as a rule made with test pieces machined cold from that part of the tire which has been deformed least in the impact test and has been straightened again, being gently heated for the purpose.

The impact tests are as rule made in the same way with all kinds of steel; blows of 3,000 kilogrammetres (21,700 footpounds) each are given (in some cases the force of the blows is increased with each successive blow), and it is specified that after six blows, or after a certain number of blows, a definite reduction of diameter is produced. This reduction is fairly generally specified as 12 per cent in the case of Martin steel; in the case of crucible steel and special steel it is sometimes specified as 9 per cent, sometimes as 12 per cent, sometimes as $\left(\frac{D}{100} - \frac{d - 65}{10}\right)$ per cent (for the meaning of these letters, see under Prussian State Railway).

The Hungarian State Railway specifies four 3,000 kilogrammetre (21,700 footpounds) blows for wheel tires of hard crucible steel and of chrome steel; and a reduction of diameter of 12 per cent, without specifying the number of blows, for Martin steel and softer crucible steel (as regards tensile strength, see below). The

Dutch State Railway specifies for narrow-gauge wheel tires an ultimate tensile strength of 80 to 90 kilograms per square millimetre (113,780 to 128,000 lb. per square inch); a tup of 500 kilograms (1,100 lb.) is used, the height of drop being 3 metres (10 feet) for the first blow, 6 metres (19 ft. 8 in.) for the second blow and 9 metres (30 feet) for the third and fourth blows, and this is to result in a reduction of diameter of 10 per cent. In the case of locomotive tires it specifies an ultimate tensile strength of 68 to 74 kilograms per square millimetre (96,715 to 105,250 lb. per square inch); after four blows of 6,000 kilogrammetres (43,400 foot-pounds) each or of 10,000 kilogrammetres (72,330 foot-pounds) each (according to diameter) the reduction of diameter is to be 18 per cent. In the case of carriage tires it specifies an ultimate tensile strength of 55 kilograms per square millimetre (78,225 lb. per square inch), and four blows of 3,000 kilogrammetres (21,700 foot-pounds) each are to give a reduction of diameter of 12 per cent.

In some cases no specifications are yet drawn up for tires of specially-high resistance.

Ball-hardness tests are only mentioned by the Hungarian State Railway; it is stated as desirable that chrome steel having a minimum ultimate tensile strength of 70 to 90 kilograms per square millimetre (99,560 to 128,000 lb. per square inch) should show a hardness of at least 150, as compared with one of 185 in the case of Martin steel having a minimum ultimate tensile strength of 55 kilograms per square millimetre (78,225 lb. per square inch). These tests are made on cross-sections.

As a rule, two per cent of the tires supplied are tested, whatever the kind of steel, and at least one tire of every heat or of every lot supplied; the Prussian State Railway and the Alsace-Lorraine State Railway specify a greater number of tests, namely 4 per cent, in the case of crucible-steel tires.

The period of guarantee is generally the same whatever the kind of steel, and amounts to three or four years; the Baden State Railway requires two years in the case of crucible steel and five years in that of Martin steel.

Only few data are available as to the distance run for each millimetre of wear. Any comparison of the figures given in this report is made very difficult by the preponderating influence of the nature of the track (compare the figures given for mountain lines by the Austrian Southern Railway) and by the fact that the special steels and the ordinary steels are used under different conditions. The special steels of higher resistance at present used in current practice are generally considered as of equal merit. Sufficient data are not yet available as regards the wheel tires of specially-high resistance which are now being tried in many cases. Comparative trials have only been begun recently on most of the railways. Among the comparative trials which have been completed, those of the Aussig-Teplitz Railway, made on locomotive tires, have shown that crucible steel and special Martin steel having a minimum ultimate tensile strength of 70 kilograms per square millimeter (99,560 lb. per square inch) show a superiority of 40 per cent

as compared with basic Martin steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch). Trials made on the Alsace-Lorraine State Railway on locomotive tires, have also shown that crucible steel having a minimum ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch) shows a superiority of 50 per cent as compared with acid Martin steel having a minimum ultimate tensile strength of 50 kilograms per square millimetre (71,114 lb. per square inch); nevertheless Martin steel is considered quite good enough except in the case of tires having a diameter exceeding 1,500 millimetres (4 ft. 11 in.) and of the tires of the carrying wheels of express and passenger locomotives.

The information supplied about the defects produced during use does not enable us to draw any distinctions between the different kinds of steel. Complaints are very generally made that the tires of the small carrying wheels of locomotives, if heavily loaded, soon become damaged by becoming laminated; but no connexion between this fact and the kind of steel used is apparent.

V. — Springs.

As the limit of 60 kilograms per square millimetre (85,336 lb. per square inch) adopted in the other cases cannot be applied to springs, we have included those kinds of steel which can in any sense be looked upon as special, as of greater value.

A sharp line cannot be drawn in this case, for the reason that reliable data as to method of manufacture are seldom available, that in some cases the manufacturers keep the methods secret, and that chemical analysis and microscopical analysis, which could give some information on the subject, are as yet but little used outside steel works. According to the opinion of the reporter the limit, under these conditions, should be traced large and to some extent trivial, so as to include all those kinds of steel which may for any reason be expected to have properties superior to those of the kinds of steel ordinarily used for the same purpose. Accordingly we will consider as special steel of high resistance, the following kinds of steel :

a) Steel which has received a special name owing to an addition made with a view to its improvement, or owing to its chemical analysis;

b) Steel which is designated by its manufacturers special steel, or extra steel, without giving any further particulars;

c) Those kinds of steel, which are manufactured by a process intended to improve its quality, as for instance crucible steel.

No steel belonging to class *a*) is mentioned in the answers sent to our list of questions under the heading " springs ".

The Baden State Railway has since 1907 been using crucible steel of higher resistance for all the springs, draft and buffing gear included, of the new locomotives of

classes IV*f*, VIII*e*, and X*b*, that is for 7·25 per cent of the total locomotive stock; this steel must stand hardening in water and is treated in the same way as ordinary spring steel.

—	Martin or Bessemer steel.	Crucible steel.
In unhardened condition :		
Ultimate tensile strength, in kilograms per square millimetre.	65	75
Elongation, in per cent, measured on a length of 200 millimetres	10	12
Tensile strength plus twice elongation, at least.	95	105
Bending test	A hardened plate placed on two supports 600 millimetres apart is acted on by a load of 0·12 bh^2 kilograms. No permanent set must be produced.	
Number of tests	2 per cent.	
Tests for special springs	Repeatedly pressed tight up ; the set produced must not exceed 2 millimetres.	

The Bavarian State Railway uses for 20 per cent of its locomotive stock special spring steel ; the heavily-loaded bearing springs of the more recent locomotives are exclusively made of special steel.

—	Martin steel.	Special steel.
In unhardened condition :		
Ultimate tensile strength, in kilograms per square millimetre, at least.	65	85
Elongation, per cent, at least	10	12
Tensile strength plus twice elongation, at least.	95	115
Temperature for hardening	Dark red heat	810-870° C.
Temperature of water in which quenched	18-22° C.	40-50° C.
Temperature to which tempered	200° C.	450-500° C.
Calculated stress, in kilograms per square millimetre	50-55	up to 63

Samples of individual plates are tested. A Martin-steel plate having a cross-section of 90 × 13 millimetres ($3\ ^9/_{16}$ inches × $^1/_2$ inch) is placed on two supports

600 millimetres (1 ft. 11 $^5/_8$ in.) apart and acted on by a load of 1,800 kilograms (3,968 lb.); no permanent set must be produced. Special-steel spring plates are subjected to a similar bending test; a stress of 120 kilograms per square millimetre (170,674 lb. per square inch) acts on the most strained fibre. Every newly-finished or repaired spring is tested for deflection and sagitta under gradually-increasing loads; the loaded spring is oscillated several times, and then slowly loaded; the sagitta must not decrease by more than 2 to 3 millimetres ($^3/_{32}$ to $^1/_8$ inch).

The modulus of elasticity of the special steel for springs is 20,700 kilograms per square millimetre (29,441,237 lb. per square inch).

The elastic deflection as compared with similar springs of ordinary spring steel used is about 20 per cent greater; fractures and crippling occur more rarely.

The Oldenburg State Railway is using for passenger carriages, as an experiment, plate springs having a length of 1,900 millimetres (6 ft. 3 in.) when extended, made of special steel, medium grade, supplied by works B, hardened in water.

The ultimate tensile strength is at least 85 kilograms per square millimetre (120,890 lb. per square inch) and the elongation at least 12 per cent. Tensile strength plus twice the elongation must give at least 115.

A hardened plate having a cross-section of 90 × 13 millimetres (3 $^9/_{16}$ inches × $^1/_2$ inch) is placed on two supports 600 millimetres (1 ft. 11 $^5/_8$ in.) apart, and acted on by a load of 2,200 kilograms (4,850 lb.); no permanent set must be produced.

No results are as yet available.

The Prussian State Railway is at present making extensive trials with special steel supplied by works A and B, the steel being subjected to greater stresses than the ordinary spring steel. Plate springs made of this steel are being tried on eight-wheel and on twelve-wheel corridor carriages, on the bogie trucks of superheated-steam locomotives and on the superheated-steam goods locomotives with eight wheels, all coupled, of class D. The comparative experiments on the system of hardening are not yet concluded; but hardening in oil seems to give good results.

—	Ordinary spring steel.	Soft special steel.	Medium hard special steel.
In unhardened condition :			
Ultimate tensile strength, in kilograms per square millimetre, at least.	65	75	85
Elongation, per cent, at least	10	14	12
Tensile strength plus twice the elongation, at least	95	105	110
	Must be suitable for water hardening.		

Loading tests are carried out on 5 per cent of the finished springs by means of a lever press; the springs are on hangers and subjected to the same stresses as when in actual use on the vehicles, and so arranged that the angles of the hangers can be observed during the loading operation. The load must correspond to a fibre stress of a least 100, 120 and 130 kilograms per square millimetre (142,230, 170,674 and 184,900 lb. per square inch), in the cases of ordinary spring steel, soft special steel and medium-hard special steel respectively.

The springs must show no permanent set after unloading.

The further use of this steel will depend on the results obtained.

The Alsace-Lorraine State Railway uses for all longitudinal springs (4) and double transverse springs (twice 3) of the bogie carriages with eight wheels, of the standard Prussian pattern, special spring steel (crucible steel) which is subjected to stresses of 55 (longitudinal springs) and 66 (transverse springs) kilograms per square millimetre (78,225 and 93,870 lb. per square inch).

The springs are hardened in lukewarm water and in the same way as in the case of ordinary spring steel.

In unhardened condition.	Crucible steel.	Martin or Bessemer steel.
Ultimate tensile strength, in kilograms per square millimetre, at least	75	65
Elongation, per cent, at least	12	10
Tensile strength plus twice the elongation, at least	105	95

A hardened plate having a cross-section of 90 × 13 millimetres (3 $^{9}/_{16}$ inches × $^{1}/_{2}$ inch) is placed on two supports 600 millimetres (1 ft. 11 $^{5}/_{8}$ in.) apart and acted on by a load of 1,800 kilograms (3,968 lb.). No permanent set must be produced.

Loading tests of the finished springs are made in the same way as on the Prussian State Railway; the fibre stress must be at least 110 kilograms par square millimetre (156,450 lb. per square inch) in the case of special spring steel, as compared with 100 kilograms per square millimetre (142,230 lb. per square inch) in the case of ordinary spring steel.

The carriages with crucible-steel springs run smoothly and steadily. The fatigue of the springs on corridor carriages with eight wheels was materially reduced by adding an extra plate to each spring; and by turning the bogies, so that the springs exchange position as regards direction and side, the fatigue is equally distributed over the springs, so that it becomes seldom necessary to adjust them. Fractures of springs occur comparatively rarely.

The Wurtemberg State Railway uses special steel mark S. I. H. 6 supplied by works B for the springs of the trailing coupled axles of the $^{3}/_{4}$ coupled rack tank locomotives, and for the $^{3}/_{3}$ coupled tank locomotives with flexible axles, of the Klose design (these springs are made of the same design and dimensions as the springs originally used, made of ordinary spring steel, which soon became fatigued when used), for the bearing and check springs of bogie carriages with eight wheels,

for the bearing springs of the new four-wheeled mail vans and for a number of new four-wheeled goods wagons.

—	Specification.		Results of tests.	
	Unhardened.	Hardened.	Unhardened.	Hardened.
Ultimate tensile strength, in kilograms per square millimetre	85 to 100	At least 140	(85·4) 92 (105)	(140·5) 151 (168)
Elongation, per cent	At least 12	— 5	(9) 12·5 (14·5)	(3) 5 (6·6)

Tenside tests are made of 10 per cent of the springs; half of these are hardened and half unhardened.

—	Special steel.	Ordinary spring steel.
Admissible stresses for :		
Carriage bearing springs, in kilograms per square millimetre	86	72
Check springs, in kilograms per square millimetre	96	80
Admissible fibre stress (during the loading test), in kilograms per square millimetre	120	100
Hardening and tempering process . .	Heated in furnace to 850° C. (bright red heat), quenched in water at 40 to 50° C. then into oil bath. Slowly heated to 450-500° C. and slowly cooled in the air.	Heated to bright-red heat and quenched at 30 to 40° C. Heated in tempering furnace, till rape oil squirted on catches fire, and then dipped into water at 30 to 40° C.
Bending test, separate plates	A hardened plate (one out of every 1,000 kilograms of springs) having a cross-section of 90 × 13 millimetres, or of 90 × 9 millimetres, is placed on two supports 600 millimetres apart and acted on by a load of 2,200, or of 1,000 kilograms respectively; no permanent set must be produced.	...
Bending test, finished spring	5 to 10 per cent of the springs are taken, the deflection produced by two different loads is measured, and the springs are loaded till fully extended; no alteration in the original camber must be produced.	

These specifications were hitherto satisfied in all the tests that were made.

As compared with the springs made of ordinary spring steel, the springs made of special steel prove more elastic in use, the vehicles run more smoothly, fatigue of the springs and the fracture of individual plates are far rarer, and it is seldom necessary to readjust them. The special-steel springs used on the four-wheeled goods wagons, after the first two years of use, showed an average reduction of camber of about 2·5 millimetres ($^3/_{32}$ inch).

It is not intended to extend, for the time being, the use of special-steel springs on locomotives; but all eight-wheeled express carriages and mail vans, as well as the new four-wheeled mail vans, are to have such springs.

The Aussig-Teplitz Railway uses special steel supplied by works E for the springs of driving and coupled axles of locomotive class III*a*, which have become heavier in consequence of reconstruction.

One tensile test, hardened, and one tensile test, unhardened, are to be made to each 150 springs.

—	Unhardened.	Hardened.
Specified :		
Ultimate tensile strength, in kilograms per square millimetre, at least	70	115
Elongation, per cent, at least	10	6
Contraction of area, per cent, at least	20	10

One bending test to each 150 springs is to be made as follows : a plate 1 metre (3 ft. 3 $^{3}/_{8}$ in.) long is bent hot so as to have a sagitta of 100 millimetres (3 $^{15}/_{16}$ inches), and then hardened in the same manner as the plate springs. It is then loaded so as to obtain a fibre stress of 100 kilograms per square millimetre (142,230 lb. per square inch); the load is then increased by 100 kilograms (220 lb.) at a time till the fibre stress is 125 kilograms per square millimetre (177,785 lb. per square inch). The limit of elasticity is considered to be attained when a permanent set of 0·5 to 1·5 millimetres ($^{1}/_{64}$ to $^{1}/_{16}$ inch) is produced. After this has been attained, the load is increased by 200 kilograms (440 lb.) at a time until the maximum calculated fibre stress is 200 kilograms per square millimetre (284,456 lb. per square inch). Till then the plate must not break.

These springs of special steel are far superior to the springs of ordinary steel.

The Austrian North Western Railway (1) has since 1902 been using bearing springs made of special steel, on three sleeping cars and three dining cars of the International Sleeping Car Company; this special steel is called Holtzer steel, and nothing is known as to how it is tested; but good results have been obtained and cases of fracture have been exceedingly rare.

The Austrian State Railway is using bearing springs of special steel on one class of locomotive, on five saloon cars and on five corridor carriages (with eight and four wheels), as an experiment; this special steel is supplied by works E; the fibre stress is 62 to 75 kilograms per square millimetre (88,180 to 106,670 lb. per square inch) when the cars are empty, 80 to 89 kilograms per square millimetre (113,780 to

(1) The lines of this system have since been incorporated in the system of the Austrian State Railway.

126,580 lb. per square inch) when they are loaded, and 80 to 120 kilograms per square millimetre (113,780 to 170,674 lb. per square inch) during the tests.

The trial locomotives, when ordinary spring steel was used, repeatedly had springs broken, and it was necessary, on the average, to replace the springs every year; the springs made of special steel had been in use for two years when the list of questions was answered, without trouble of any kind.

The Hungarian State Railway uses in current practice special steel having an ultimate tensile strength of 145 kilograms per square millimetre (206,230 lb. per square inch) and an elongation of 5 per cent in the hardened and tempered condition, for the springs of locomotives and of wagons of large capacity.

The bending test is made on plates 1 metre (3 ft. 3 $^{3}/_{8}$ in.) in length, the fibre stress being 80 kilograms per square millimetre (113,780 lb. per square inch). In addition an impact test is made on a plate 200 millimetres (7 $^{7}/_{8}$ inches) long, which is hardened and tempered like the plate springs; it is placed on two supports which are 100 millimetres (3 $^{15}/_{16}$ inches) apart; three blows are given by a tup weighing 50 kilograms (110 lb.) and falling from a height of H centimetres,

$$H = \frac{\text{cross-section in square millimetres}}{4}$$

on to the one side; the plate is then turned over and three similar blows are given on the other side; neither fracture nor cracks must result.

Nothing is yet settled as to the further use of such springs.

The Dutch State Railway exclusively uses special steel in current practice for the bearing and check springs of eight-wheel passenger carriages.

—	Specified minimum values.	
	Unhardened.	Hardened.
Ultimate tensile strength, in kilograms per square millimetre. .	80	130
Limit of elasticity, in percentage of ultimate tensile strength.	50	...
Elongation, per cent, measured on a length of 200 millimetres .	15	6
Contraction of area, per cent	32	22
Tensile strength plus elongation	100	140

The phosphorus and sulphur content must at most amount to 0·035 per cent.

Fibre stress 66 to 81, and 65 to 79 kilograms per square millimetre (93,870 to 115,200, and 92,450 to 112,360 lb. per square inch) respectively. No difference is made as compared with ordinary spring steel; not even in hardening and tempering.

A test plate 750 millimetres (2 ft. 5 $^{1}/_{2}$ in.) long is bent to a radius equal to 50 times the thickness and hardened and tempered; it is then pressed flat once and

again released, and the sagitta measured. It is then pressed flat and again released ten times in succession in one minute; the sagitta must be the same as that first measured.

Of the bars, 2 per cent are tested, or at least one bar of each heat.

All the finished springs are tested statically to see that they have the proper sagitta under the working load. They are then loaded with one and a half times the working load and released ten times in succession in one minute; the sagitta must not be greater than after a preliminary first loading and release.

It is not intended to extend this application to other vehicles.

The Rumanian State Railway uses for springs crucible steel having an ultimate tensile strength of 75 to 80 kilograms per square millimetre (106,670 to 113,780 lb. per square inch).

SUMMARY.

Springs made of special steels of higher resistance are used by ten railway administrations, on locomotives chiefly in those cases where other springs gave trouble, or where loads were increased and it was desired to avoid the use of larger springs, and also on passenger carriages, more especially and to a considerable extent on bogie carriages with eight wheels. The Wurtemberg State Railway and the Hungarian State Railway also use special steel for the bearing springs of wagons of large capacity. The Baden State Railway also uses it for the draft and buffing gear springs of several new classes of locomotives.

Several of the railway administrations in Germany are in accordance in specifying for unhardened special spring steel a minimum ultimate tensile strength of 75 kilograms per square millimetre (106,670 lb. per square inch) with a minimum elongation of 12 to 14 per cent, and a minimum ultimate tensile strength of 85 kilograms per square millimetre (120,890 lb. per square inch) with a minimum elongation of 12 per cent; usually they also specify that tensile strength plus twice the elongation should be 105, or 110 to 115 as a minimum. The former kind is denominated soft special steel and the latter medium-hard special steel; the fibre stresses specified in the bending tests are 10 to 20 per cent higher in the former case, and 30 per cent higher in the latter case, than with ordinary spring steel. The Hungarian State Railway specifies impact tests in addition to bending tests, for the special spring steel. As regards the number of tests made, no difference is made between this steel and the ordinary spring steel.

As regards working stresses, these are in many cases not higher than before, as it is often a question of cases in which the material hitherto used did not give satisfactory results. The highest working stress is mentioned by the Wurtemberg State Railway, namely 96 kilograms per square millimetre (136,540 lb. per square inch) (as compared with 80 kilograms per square millimetre [113,780 lb. per square inch] in the case of ordinary steel) in the case of check springs made of special spring steel, having on the average an ultimate tensile strength of 92 kilograms per square

millimetre [130,850 lb. per square inch] in the unhardened and of 151 kilograms per square millimetre (214,765 lb. per square inch) in the hardened condition, and about 20 per cent more elastic deflection than ordinary spring steel. As regards the hardening process, conclusive results do not yet appear to have been arrived at; satisfactory results are reported both in the case of water hardening and in that of oil hardening. In nearly every case, the details of the hardening process and the temperatures are more accurately fixed than in the case of ordinary spring steel.

The results in practice are consistent and exceedingly favourable : greater elasticity, easier and smoother running of the vehicles. Fatigue and fractures are much rarer, and readjustment is much more seldom necessary.

VI. — **Miscellaneous parts.**

The Baden State Railway has since 1907 been using crucible steel for the connecting rods and valve rods, cranks and return cranks, eccentric rods, crank pins and coupling pins, cross-head gudgeon pins and axle keys, of 7 per cent of the locomotives. This steel has an ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch), an elongation of 20 per cent and a contraction of area of 35 per cent; it must be possible to bend a strip to form an eye having a diameter equal to half the thickness of the strip; 2 per cent of the number of articles supplied must be tested but not less than two articles, or two articles of every heat. Nickel steel is used for the coupling rods of locomotives classes IV*f* and VIII*e*; this nickel steel must have at least an ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch), an elongation of 18 per cent and a contraction of area of 45 per cent, and tensile strength plus contraction must give at least 110, as is also specified in the case of nickel steel for axles.

Results are not yet available, as these articles have only been in use a short time; but these articles will in the future be made of the same materials.

The Prussian State Railway uses for the superheated-steam locomotives equipped with Schmidt superheater, crank pins and coupling pins having a dead-hard surface extending to a depth of 4 to 6 millimetres ($^5/_{32}$ to $^1/_4$ inch); they are either, " compound steel " made by works C by a special process, which results in producing a very close texture in the hard surface, or made from a special mild steel (ingot iron) produced by works A and B, in the Siemens-Martin furnace for casehardening purposes.

These pins stand a much higher pressure per unit of surface and show much less wear than pins of steel of natural hardness; moreover the bearings, if carefully adjusted in the first instance, wear much longer and if in consequence of defective lubrification heating has taken place and cracks have formed, they can continue to be used after the sharp edges of the cracks have been rubbed down by means of Mississippi or Arkansas stone.

The Alsace-Lorraine State Railway uses nickel steel to some extent for cranks and pins.

The Saxon State Railway has for a long time been using crucible steel (similar to that used for locomotive tires) having an ultimate tensile strength of as least 65 kilograms per square millimetre (92,450 lb. per square inch) and an elongation of 10 per cent, for piston rods, with good results.

The Wurtemberg State Railway as an experiment used nickel steel for the coupling pins of ten locomotives, type 1 B 1, of the Klose design; the original dimensions are retained.

These pins were taken out, partly on account of fracture and of cracks (the reasons for which remained unknown) after having been in use six to seven years (250,000 to 350,000 kilometres [155,300 to 217,500 miles]), partly on account of wear, after having been in use six tot welve years. Sitst now, comparative experiments are being made with case-hardened Martin ingot iron. It is at present not intended to make any more parts of special steels of high resistance.

The Austrian State Railway uses return cranks of crucible steel.

The Austrian Southern Railway uses crucible steel having an ultimate tensile strength of 60 to 70 kilograms per square millimetre (85,336 to 99,560 lb. per square inch), a minimum elongation of 14 per cent and a minimum contraction of area of 32 per cent, for return cranks and cross-head gudgeon pins, in some cases also for crank pins and coupling pins; it also uses basic Martin steel having an ultimate tensile strength of 60 to 65 kilograms per square millimetre (85,336 to 92,450 lb. per square inch), a minimum elongation of 15 per cent and a minimum contraction of area of 40 per cent for slide bars and piston rods.

Comparative trials with coupling pins made of crucible steel and of case-hardened basic Martin ingot iron are in progress.

The Hungarian State Railway uses special steel (nickel steel similar to that used for axles) for the crank pins and coupling pins, and Abt pinion wheels, of several classes of locomotives.

The Prinz-Heinrich Railway uses 3 per cent nickel steel for the cranks and pins of locomotives (for 9 per cent of the cranks), the dimensions being the same as in the case of ordinary steel. This nickel steel, owing to its greater hardness, resists blows better; nothing has yet been decided as to its more extended application.

SUMMARY.

Crucible steel having a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,336 lb. per square inch) is used by several administrations for piston rods, valve rods, cranks, return cranks, eccentric rods, crank pins and coupling pins, cross-head pins, etc. Special results are not yet available.

Nickel steel is used by the Baden State Railways for coupling rods, by the Wurtemberg State Railways for the coupling pins of some new classes of locomotives, by the Hungarian State Railway for crank pins, coupling pins and Abt pinion wheels, and by the Prinz-Heinrich Railway for cranks and pins; as a rule, the same

qualities are demanded as in the case of the nickel steel used for axles, about which no conclusive opinion can yet be formed. The favourable results obtained by the Prussian State Railways with pins made of compound-steel or of special mild steel for case-hardening purposes, used on their superheated-steam locomotives which do very heavy work, are worth noticing.

VII. — **Concluding remarks.**

The preceding information shows that definite conclusions as to the behaviour of different kinds of steel in actual practice can only be drawn in the case of springs, but meet with great difficulties in other cases, owing on the one hand to the dependence of the results obtained in practice on the varying conditions of the traffic, and on the other, to the fact that the results of the tests now usually carried out do not allow the behaviour in actual working to be surely deduced.

It is found, in particular, that the varying designs of the rolling stock and of the separate parts, together with the varying conditions of the line, especially as regards gradients, curves and other conditions, as a rule have as strong an influence, or even a stronger influence on the life of the parts, than the nature of the material of which they are made.

Reliable information about the comparative value of different materials can therefore as a rule only be obtained, if the materials to be compared are used methodically under exactly equal conditions of working, and if care is taken that the measures and observations are taken in exactly the same way by responsible parties.

It is advisable, with this object in view, to use carefully worked out and detailed forms when making comparative trials, making if necessary preliminary experiments to serve as basis; the work made necessary by the experiments can, under the system adopted by the Prussian State Railway (1), be counterbalanced by omitting the complicated records concerning all the rolling stock, which already give to great administrations so much work to do, that they cannot be properly worked out. The risk that the rolling stock used for the comparative trials is lost sight of and that the evidence in question is lost can, according to the statement of the Baden State Railway (2), the better be obviated by marking the stock in question in a conspicuous way, for instance by a red circle, to denote that it is the subject of expriment, and by supplying it with a recording document, for instance in the case of a carriage a paper-case, in that of a locomotive by entry in the locomotive book.

That it is possible in this way to obtain sufficient evidence in a comparatively-short time with a comparatively-small number of trial objects, unless the traffic and line

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(1) As regards the importance of fully-detailed forms to the administration of the Prussian State Railway, see Hoff : « Zur Wiederkehr des zehnten Jahrestages der Neuordnung der preussischen Staatseisenbahnverwaltungen », in *Archiv für Eisenbahnwesen*, 1905, p. 307.

(2) *Zeitung des Vereins deutscher Eisenbahnverwaltungen*, 1908, No. 87, p. 1382.

conditions are particularly unfavourable, or unless the rolling stock is very diversified, is shown by the comparative trials mentioned in section IV, which were carried out by the Alsace-Lorraine State Railway on the tires of ten locomotives during a period of eight months; on the other hand, if information as to the value of a given kind of steel is to be deduced from the general traffic results, then taking the quick development of steel production into consideration, this information is often obtained at a time when that particular steel is no longer made in the same way.

The chief difficulty of such comparative trials is probably that it is not easy to carry them out without allowing for them to some extent in the arrangement of the traffic. On the other hand however, this is at all events justified by the great economic importance of any increase in the life of any parts of the rolling stock. It would be very desirable to make the results as comparable as possible by laying down uniform conditions under which the trials should be carried out, so that the information desired could be obtained without obliging any individual administrations to carry out too great a number of experiments; in this way, lines with heavy traffic, regular conditions and always using the same stock, for instance suburban lines, could do very valuable service.

A second difficulty, of not less magnitude, consists in deciding whether a material is superior or inferior, as regards those properties which are of importance as regards its behaviour in actual practice. As the railway administrations on whose answers this report is based, with few and unimportant exceptions, do not include in their specifications any clauses as regards processes of manufacture, and accordingly only make a comparatively-small use of chemical analysis for describing the material, it is the mechanical testing which is chiefly to be considered.

The tensile test, determining the ultimate tensile strength, gives a measure for the resistance of the material to static loads; the elongation and still more the contraction of area of the cross-section (to which sufficient attention has probably not been paid of late) give a measure for the capacity of the material to alter its shape under static load without destruction of its coherence, and so to equalize dangerous irregularities in the distribution of the stresses. To the determination of the yield point little attention has as yet been paid in specifications.

The impact test gives a measure (in the case of axles, by the deflection, or by the sum total of the deflections in both directions; in the case of tires, by the reduction of diameter) for the capacity of the material, when acted on by a small number of very violent blows, to change its shape without destruction of its coherence.

According to the results of these tests that material is to be considered superior, which in the case of tensile tests shows for the same ultimate tensile strength the greater elongation or contraction of area, or which in the case of impact tests shows for the same sum of blows, or before it begins to crack, the greater deformation.

Experience has however shown, rather consistently, that materials giving good results when tested by no means always give good results in actual use.

It occurs not rarely that kinds of steel which showed a great capacity for change of form when tested by the tensile test or even by the impact test, show a tendency to fracture and to the formation of cracks, when subjected to the numerous blows, acting in different directions and at high speeds, which occur in practice; this is especially the case if there are abrupt changes in the cross-section, or some important discrepancy from the form of uniform strength, small injuries to the surface or injurious extra strains.

It has also been found that testing one out of fifty articles or even one out of twenty-five articles (as specified by some administrations in the case of crucible steel) by no means makes it sufficiently certain that the other articles have the same properties as those tested; and that with one and the same article, for instance an axle, the impact test may give very good results as regards the middle parts of that axle, while its ends may have quite different properties.

Finally, experience has shown in the case of tires that an important property, that of resisting wear, bears no apparent relation to the properties determined by the tests. It is even often asserted that the usual form of impact test is in flat contradiction with the requirement of great resistance to wear; although this test certainly is to be credited with contributing for a good deal to a reduction in the number of tire fractures, yet the great capacity for change of shape, which it tests, corresponds but little to the conditions in actual working.

The means which the present state of testing science enables us to employ, to overcome these disadvantages, are not numerous; yet there are a few.

In the first place, there are the pressure hardness tests (1), which it is true give parallel results, for the same class of metal, with the tensile tests, but have the very great advantage that it is possible to test any finished part at any given point without damaging it, and so determine both the quality and the homogeneity, for instance of the tires of the same axle, of a set of driving and coupled wheels, etc.

Next we have the impact test made on notched bars (2); to determine the

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(1) The ball-hardness test (see « The Brinell method of testing the hardness of metals », *Bulletin of the Railway Congress*, 1908, December, p. 1305) and the cone-hardness test (see Ludwik, *Organ für die Fortschritte des Eisenbahnwesens*, 1909, No. 14, p. 256). For the results obtained during eight years by the Prussian State Railway with the ball-hardness test as a test for the inspection of rails, see *Zentralblatt der Bauverwaltung*, 1908, No. 77, p. 515.

As regards the testing of finished parts, compare the remarks made by Noblemaire during the discussion of subject XVI (use of steel and ingot iron) at the sixth session of the International Railway Congress (Paris, 1900) and the corresponding conclusions adopted by the Congress.

(2) As regards the preliminary investigations of the French railways, on which this test is based, see *Contribution à l'étude de la fragilité dans les fers et les aciers*. Publication faite avec le concours des six grandes compagnies de chemins de fer français par la Société d'encouragement pour l'industrie nationale, Paris, 1904.

The fifth International Congress for testing material, which met at Copenhagen in 1909, adopted the following conclusions on this test:

" *A*. In order to facilitate the comparison of results of impact bending tests on notched bars, the

tendency to fracture and to the formation of cracks of pieces of unfavourable shape and in a damaged condition.

Without anticipating the further development of this question, it yet seems that these or similar tests may much help towards the selection of kinds of steel possessing greater resistance to impact and to the unfavourable conditions mentioned which can hardly quite be avoided.

Tests of the resistance to rapidly-alternating stresses and tests of the resistance to wear seem at present to offer fewer prospects (1) more perhaps tests of the closeness of texture which seem at present to give the best clue to the resistance to

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Congress recommends the use of the following rules, unless prevented by special circumstances :

1. The notched-bar impact test serves to determine the specific work of fracture or resilience referred to the square centimetre of the notched section.
2. *a*) The bars cut to sufficient length have the following dimensions : 30 × 30 × 160 millimetres (1 3/16 × 1 3/16 × 6 5/16 inches). They are notched to a depth of 15 millimetres (5/8 inch). The bottom of the notch in the bar is cylindrical and has a radius of 2 millimetres (5/64 inch).

   b) For rolled materials such as plates, the bars have the same thickness as the plate, the surfaces of which are preserved, and a width of 30 millimetres (1 3/16 inches). They are notched to a depth of 15 millimetres (5/8 inch). The notch is perpendicular to the direction of rolling and has a cylindrical bottom with a radius of 2 millimetres (5/64 inch).

   c) For pieces which do not permit the use of bars 30 × 30 millimetres (1 3/16 × 1 3/16 inches) in section, the bars are 10 × 10 millimetres (3/8 × 3/8 inch). They are notched to a depth of 5 millimetres (3/16 inch). The bottom of the notch is cylindrical and has a radius of 2/3 millimetre (1/64 inch).

   d) The size of the bars used is always to be recorded.
3. The bars are tested by bending and receive at their centre upon the side opposite to the notch the impact of the drop weight which has a knife edge rounded to a radius of 2 millimetres (5/64 inch). They rest on knife edges spaced 120 millimetres (4 11/16 inches) apart in the case of types *a* and *b* and 40 (1 9/16 inches) in the case of type *c*.
4. The fracture of the bar shall be effected by a single blow by means of an apparatus which enables the work absorbed by the fracture to be measured.
5. The temperature should be as nearly as possible between 15 and 25° centigrade (between 59 and 77° Fahr.), and in all cases shall be noted with the results of the tests.

B. The Congress recommends that a committee be appointed to collate all the results which make it possible to establish a connexion between the properties manifested during the tests and the behaviour of the pieces in service, and that this committee also study the comparison of the various apparatus."

This method of carrying out the test is practically the same as that used by Charpy (Monluçon steel works, France), with some modifications introduced by the German *Verband für die Materialprüfungen der Technik*.

(1) As regards resistance to rapidly-alternating stresses, see Mr. P. H. Dudley's report on subject I (nature of the metal for rails) to the sixth session of the International Railway Congress (Paris, 1900), and the results of the trials at the Waterton Arsenal, United States of America. As regards resistance to wear, see the conclusions of the fifth International Congress for testing materials (Copenhagen,

wear. The question of tests at higher temperature does not yet come into consideration in the present field of application of the special steels.

The procedure which is to be adopted is evidently the same which many years ago led to the introduction of the tests generally used now : the collection of the results of tests of materials which gave good results in practice, and of those of materials which gave bad results in practice (1). This is the procedure which is recommended in the last paragraph of the conclusions of the International Congress for testing materials, which is quoted above. In order to succeed in ascertaining what the most suitable tests are which really characterize the suitability of the material for actual working purposes, this procedure should be extended, for the same material, to as many different kinds of tests as possible, and the working properties of the materials should not merely be described by the general classification " good " and " bad ", but as much as possible also by numeral results of trials in practice.

In the case of special steel, as indeed in the case of all kinds of steel of greater value, the difficulties which otherwise oppose the introduction of new specifications are much reduced, because in this case the interest of the manufacturers, to prove by stricter tests the advantage of using their material, is coincident with the interest of the purchaser, to ascertain before use the real superiority of the materials offered.

There is hardly any doubt that the more expensive kinds of steel can at present already compete economically in the case of parts which frequently have to be renewed, and that the improvements, now in rapid progress, which are being made in the quality of the metal, will make available large fields of application, if this metal has the chance and the opportunity of proving its superiority for certain applications.

On the other hand, earnest attention should be paid, especially at a time when the coefficient of working is continually growing, to any possible saving resulting from a suitable selection of material, for a very small improvement in the wear, a very small increase in the life of the individual parts and the running-time of rolling stock represent, as a whole, very large sums every year.

1909), according to which a report is to be submitted to the next Congress, in 1912, about the specification of standard tests for this purpose. As regards the examination of the texture, see Mr. P. H. Dudley's report on subject II (rails for lines with fast trains) to the seventh session of the International Railway Congress (Washington, 1905), and the specification of the Philadelphia and Reading Railway Company fixing the minimum number of grains or cells per unit of cross-section, this number being determined by microscopic methods. (See also further experiments by alternating stresses with rods cut out from old rails.)

(1) Compare : *Die Eigenschaften von Eisen und Stahl-Mitteilungen über die auf Veranlassung der technischen Kommission des Vereins deutscher Eisenbahn-Verwaltungen ausgestellten Versuche nebst Entwürfen zu den Bedingnissen für die Lieferung von Schienen, Achsen und Radreifen.* Wiesbaden, 1880.

Appendix.

Record

of crank driving axle of locomotive :

LK. Class. ..... Axle No.
Material ..... Works No.
Supplied by
Year in which supplied

Approval for further use is necessary from the following date .....

The axle was marked with a cross on the following date.

The axles were				Diameter, in millimetres				Distance run : a) since last examination : b) total :	Remarks : (Number of coupled axles) :
put in :		taken out and examined :		Bearing journals		Crank journals			
Index number.	Workshop : Date :	Workshop : Date :	Result :	left :	right :	left :	right :		
								a) b)	
								a) b)	
								a) b)	

To be submitted

to the general management for authorizing the further use of the axle.

General Management.

The further use of the axle is authorized.

Date.	Place and signature.	Date.	Signature.

*

Rules for examining the crank driving axles of locomotives.

I. The crank driving axles must be taken out and examined:

1. Immediately after the trial runs of the locomotives with new crank driving axles.
2. Every time the locomotives are repaired, whenever the repairs anyhow make it necessary to take out the axles.
3. Even when the locomotives require no repairs:

   a) After running at most 100,000 kilometres (62,140 miles) since the last examination; as long as the total distance run by the axle does not exceed 550,000 kilometres (341,760 miles).

   b) After running at most 75,000 kilometres (46,600 miles) since the last examination, if the total distance run by the axle already exceeds 550,000 kilometres (341,760 miles).

II. At this examination, which has to take place immediately after the axles have been taken out, the bearings and crank bearings, and the eccentric disks have to be taken off, the axles have to be taken off, properly cleaned and then carefully examined over their whole length and whole circumference for defects or injuries (cracks, abrasions). The fillets and corners at the journals and cranks as well as at the eccentric seats and the key-ways have to be carefully examined at the same time.

The wheels and axles are to be slowly rolled, for at least one whole revolution, on rails on which wooden wedges 3 to 5 centimetres (1 $^3/_{16}$ to 2 inches) thick are placed, so that the wheels and axles receive shocks; if any cracks exist these will then be shown by drops of oil or threads of oil appearing at the bright surface of the axles.

The examination of the cranked axle is to be carried out by the works inspector or by a works foreman.

The bearing and crank journals of the crank axle must not be trued till after they have been examined. The diameters of the journals are accurately measured after the turning. The measuring instruments used for this purpose must be compared once a year with those of the chief shops, which is entrusted with their adjustment.

III. The results of the examination of the crank driving axles, as well as diameters of their journals are to be entered in a report, a separate report being made for each axle. This report is added to the record book of that locomotive for which the axle is then used.

The distance run by the axle, taken from the locomotive record book, is to be entered in the report of the examination of the axles.

Forms for this examination report are to be obtained from the technical office.

If the axles are bent, loose at the wheel seat, or if the wheels have become displaced, further if there is any objection to the axle owing to the presence of cracks or of material abrasions as well as in cases where the extent of the damage is doubtful, the wheels and axle are to be sent to the chief workshops together with the corresponding coupled axles.

IV. The further use of the crank driving axle, which has been found in good condition, is then to be proposed to the general management, the report of the examination being submitted at the same time:

1. If the axles at the time of examination have already run a total distance of 750,000 kilometres (466,000 miles), or will very soon have run that distance.
2. If the journals of the axles have been turned down to

Class of axle	Axle bearing.	Crank bearing.
II *c* and IV *e*	177 millimetres. (6 $^{31}/_{32}$ inches).	195 millimetres. (7 $^{11}/_{16}$ inches).
II *d*	205 millimetres. (8 $^1/_{16}$ inches).	215 millimetres. (8 $^7/_{16}$ inches

If the application for the further use of the axle is approved, this is notified by a cross (+) about 1 centimetre ($^3/_8$ inch.) in size; which is punched under the number and material marks on the axle. This has to be entered in the report of the examination.

The examination of the axles is to be continued in the way described above and the application for the further use has to be renewed:

1. When the axle has run another 75,000 kilometres (46,600 miles).
2. If even only one of the journals of the axle has had to be turned smaller than the dimensions above given or exceptionally allowed.

V. The regular repeated pressing off of the wheels of the crank axles and of the corresponding coupled axles after running a certain definite distance is no longer to be effected.

The wheels of the crank driving axle are only to be pressed off for the examination of the wheel seats when the axles are withdrawn for service. But in this case the wheels of the coupled axles corresponding to this driving axle are also to be pressed off, if these coupled axles have been in use for nearly ten years or longer.

[621 .131.2 & 625 .246]

REPORT N° 6

(Great Britain)

By Wilson WORSDELL,
CHIEF MECHANICAL ENGINEER, NORTH EASTERN RAILWAY.

The writer had the honour of being requested by the General Secretary of the Permanent Commission of the International Railway Congress, to furnish a report on the use of special steel of high resistance for various parts of rolling stock, so far as Great Britain was concerned.

The compiling of this report was undertaken and lists of questions sent round to various Railway Companies. In the first place, the point to be decided was, what is the minimum ultimate stress that steel must have in order that it may be termed " special steel of high resistance. " The figure agreed on by Messrs. Hönigsberg and Le Blant was 60 kilograms per square millimetre, or 38 tons per square inch approximately, this figure the writer was willing to accept with two exceptions, these being the material for tyres and springs as it was considered that this construction could not truly apply in these cases and that it would be simply wasting the time of the congress to report on material that had been used in general practice for years, and that only tyre steel giving an ultimate tensile stress above 50 tons per square inch (79 kilograms per square millimetre) could at the present time be looked upon as special, considering that tyres are now manufactured of steel giving an ultimate tensile stress of 65 and even 70 tons per square inch, and that spring steel should either contain a special addition such as chromium, nickel or vanadium, or else contain more than 0·8 per cent carbon before it could properly be termed special.

The advantages possessed by these special steels are that some can be made exceedingly hard and yet not too brittle, and thus parts do not require such frequent renewal. Other varieties can be made of high tenacity and toughness, thus allowing existing parts to be lightened without decreasing the strength, and

in some cases rendering a design possible, certain parts of which, owing to lack of space, could not be made large enough for adequate strength in ordinary material. Obviously, the manufacturers of these special steels ask considerably higher prices than they do for material of more ordinary quality, so a demand for this class of material can only exist when limitations of weight or size or excessive wear render more ordinary material inadequate. It is possible to case-harden most parts where excessive wear takes place, so the application of special steel to save wear is confined practically to tyres, and castings with wearing surfaces. As the lines in Great Britain are of comparatively easy curvature, the tyre wear is not excessive, so very hard steel tyres are not a necessity and owing to the substantial nature of the permanent way, there are not the same limitations in axle load as exist in other countries so up to the present ordinary materials have been found adequate.

Having regard to these conditions, it will be seen that there is not up to the present much demand for special steel of high resistance in Great Britain, and the writer therefore to his sincere regret had to advise the General Secretary to the Permanent Commission of the Congress that on account of insufficient material on which to base a report, he was unable to furnish one; as however he was attending the congress as a delegate, it was thought that a short list of the cases in which special steel of high resistance is being used in Great Britain might be of some interest, and particulars are given below.

Crank axles. — Built-up type.

The Great Western Railway Company have some axles of the built-up type, the ultimate tensile stress of the steel being 45 to 50 tons per square inch (71 to 79 kilograms per square millimetre).

No comparative figures as to mileage are yet available for these axles.

The London & North Western Railway Company use axles of the built-up type, the ultimate tensile stress of the steel with the exception of that used for the webs being 37 to 44 tons per square inch (58·5 to 69·5 kilograms per square millimetre).

The steel contains 0·25 per cent of chromium. The webs are made from steel of much softer quality. No comparative figures as to mileage are available.

Several of the Railway Companies are now using crank axles of the solid type, made from steel having an ultimate tensile stress of 35 to 40 tons per square inch (55·3 to 63·2 kilograms per square millimetre) in accordance with the Engineering Standards Committees, recommendations, but these have not been in use a sufficiently long time to get reliable data as to their life.

Straight axles.

The London & North Western Railway Company use steel of 37 to 44 tons per square inch (58·5 to 69·5 kilograms per square millimetre) for locomotive straight axles, the steel contains 0·25 per cent of chromium.

Straight axles manufactured of steel of 35 to 40 tons per square inch quality (55 to 63 kilograms per square millimetre) are now in fairly general use for locomotives and carriages on most of the railways and give a life of approximately 450,000 miles on the coupled wheels of express passenger engines.

Tyres.

The Midland Railway Company are using locomotive tyres manufactured from steel of 55 to 60 tons per square inch quality (87 to 95 kilograms per square millimetre), but can yet give no particulars as to life.

The Great Central Railway Company have a few carriage tyres made of steel of 54 to 60 tons quality (85·3 to 95 kilograms per square millimetre) but have no data as yet regarding their life.

Several of the Railway Companies are now using tyres made from steel having an ultimate tensile stress of 50 to 55 tons per square inch (79 to 87 kilograms per square millimetre) for locomotives and carriages in accordance with the Engineering Standards Committees' recommendation, but these have not yet been in use a sufficiently long time to get reliable data as to their life.

Piston rods and motion bars.

The Midland Railway Company have some piston rods manufactured of steel of 42 to 48 tons per square inch quality (66·4 to 75·8 kilograms per square millimetre).

The London & North Western Railway Company are using steel having an ultimate tensile strength of 47 to 52 tons per square inch (74·2 to 82·2 kilograms per square millimetre), for motion bars.

The Great Central Railway Company use for piston rods and motion bars, steel having an ultimate tensile strength of 42 to 46 tons per square inch (66·4 to 72·6 kilograms per square millimetre).

The North Eastern Railway Company use steel of 40 to 45 tons quality (63 to 71·2 kilograms per square millimetre) for piston rods and motion bars.

None of the companies concerned above, are able to furnish data with regard to wear on these articles.

Steel castings.

Only two companies report that they are using steel castings manufactured of steel of higher tensile strength than 38 tons per square inch (60 kilograms per square millimetre), these are the Great Central & Midland Railway Companies, the steel used being of 40 to 45 tons quality (63 to 71·2 kilograms per square millimetre).

The above cases of the use of special steel of high resistance are the only ones the writer has been able to discover and whilst being aware that the data submitted is very meagre, he trusts it may be of some little interest.

On attached sheets are shown the questions sent out to the various Railway Companies.

6 April, 1910.

APPENDIX.

Detailed list of questions relating to question V-*B*

Crank axles.

Solid type.

a) Method of steel manufacture.
b) Maximum and minimum limits of tensile stress for standard solid crank axles.
c) If you have no maximum limit what is the minimum elongation on 3 inches.
d) Carbon per cent.
e) Other special elements and percentage of each present.
f) From what points on the axle do you take tests.
g) What bend test do you specify.
h) Do you specify a fatigue test if so, what.
i) Are the ingots from which your axles are made, compressed when fluid.
j) Which do you specify after rough turning, oil tempering or annealing.
k) Do you withdraw these axles from service after a given mileage if so, what.
l) If not can you give the average mileage of solid crank axles made to your standard specification and employed on express passenger work.

Experimental type.

m) Have you got any solid crank axles of high tensile strength running experimentally, if so, give total number employed, tensile strength, elongation carbon percentage, other special elements and percentage of each present.
n) Can you give the particulars of any fatigue tests made on pieces taken from this class of axle.
o) Can you give the mileage of these axles (in relation to your standard type) when employed on similar work.
p) What is the percentage increase on price over that of your standard type.
q) Are you going to extend the use of this type.
r) Have you found that the adoption of this higher tensile steel allows of a lighter axle or have the dimensions to be kept up above that necessary for strength, on account of the bearing areas.

Crank axles (for shaft, for webs and for crank pins).

Built up type.

a) Method of steel manufacture.
b) Maximum and minimum limits of tensile stress.
c) Minimum elongation per cent on 3 inches.

d) Carbon percentage.
e) Special elements and percentage of each present.
f) Treatment after forging or rough turning.
g) From what points do you take tests.
h) What bend test do you specify.
i) Do you specify a fatigue test, if so what.
j) Do you withdraw these axles from service after a given mileage, if so what.
k) If not can you give the average mileage when employed on express passenger work.
l) What is the price of these axles relatively to that of your standard solid type.

Experimental type.

m) Have you got any built up crank axles of higher tensile strength running experimentally.
n) If so give total number.

Crank axles (for shaft, for webs and for crank pin journals).

o) Tensile strength.
p) Carbon percentage.
q) Other special elements and percentage of each present.
r) Treatment after forging or rough turning.
s) Can you give particulars of any fatigue tests made on pieces taken from this class of axle.
t) Can you give the mileage of these axles when employed on express passenger work.
u) What is the price of these axles relatively to that of your standard solid type.
v) Are you going to extend the use of this type.
w) Have you found that the adoption of this higher tensile steel allows of a lighter axle, or have the dimensions to be kept up above that necessary for strength on account of the bearing areas.

Straight axles for locomotives and tenders, for carriages and for wagons.

Standard type.

a) Method of steel manufacture.
b) Maximum and minimum limits of tensile stress.
c) Minimum elongation per cent on 3 inches.
d) Carbon percentage.
e) Other special elements and percentage of each present.
f) Treatment after forging.
g) Do you withdraw these axles from service after a given mileage, if so, what.
h) If not, can you give their average mileage (or life).

Experimental type.

i) Have you got any axles of higher tensile strength running experimentally.
j) If so what number.
k) What is the tensile strength.
l) Elongation percentage on 3 inches.

m) Carbon percentage.
n) Other special elements and percentage of each present.
o) Treatment after forging.
p) Can you give the mileage (or life) of these axles in relation to your standard type when employed on similar work.
q) What is the percentage increase in price over that of your standard type.
r) Are you going to extend the use of this type.
s) Have you found that the adoption of this higher tensile steel allows of a lighter axle or have the dimensions to be kept up above that necessary for strength on account of the bearing areas.
t) Can you give comparative results of destruction tests made on these high tensile steel axles and on those of your ordinary type.

Tyres.

a) Method of manufacture.
b) Maximum and minimum limit of tensile stross.
c) Minimum elongation on 3 inches.
d) Carbon percentage.
e) Other special elements and percentage of each present.
f) Treatment after rolling.
g) Thickness of tyres new.
h) Minimum allowable thickness.

Experimental type.

i) Have you got any tires of higher tensile strenght running experimentally.
j) If so, what number.
k) What is the tensile strength.
l) Elongation per cent on 3 inches.
m) Carbon percentage.
n) Other special elements and percentage of each present.
o) Treatment after rolling.
p) Thickness of tyres new.
q) Minimum allowable thickness.
r) Percentage increase of price over that of your standard type.
s) Are you going to extend the use of this type.
t) What is the average mileage before turning up that you get out of your standard tyres on the driving wheels of express passenger engines.
u) What per cent of increased mileage do you get for equal amounts of wear with the higher tensile steel tyres when employed under the same conditions of service.
v) Can you give comparative results of destruction tests made on the higher tensile steel tyres, and on those of your ordinary type.

Boiler plates.

a) Do you use steel of higher tensile stress than 32 tons per square inch for boiler and fire-box plates.

b) If so what is the tensile strength.
c) What is the elongation per cent on 8 inches.
d) What is the carbon per cent.
e) What are the other special elements and percentage of each present.
f) Position of plates in boiler or fire-box.
g) What increased life do you get out of these plates in relation to ordinary ones.
h) What is the percentage increase in price.
i) Are you going to extend the use of them.
j) Have you trouble in flanging plates of this special quality.
k) Have you tried the use of steel of special composition or treatment (not necessarily of higher tensile strength than ordinary) to withstand the effect of corrosion.
l) If so give particulars of composition or treatment, percentage increase in price and results obtained in service.
m) Are you going to extend the use of this.

Boiler tubes.

a) Do you use steel of higher tensile strength than 30 tons per square inch for tubes.
b) If so, what is the tensile strength.
c) What is the elongation per cent on 8 inches.
d) What is the carbon per cent.
e) What increased life do you get out of these tubes in relation to ordinary ones.
f) What is the percentage increase in the price.
g) Are you going to extend the use of them.
h) Have you any trouble in expanding them.
i) Have you tried the use of steel of special composition or treatment (not necessarily of higher tensile strength than ordinary) to withstand the effects of corrosion.
j) If so, give particulars of composition or treatment, and percentage increase in price and results obtained in service.
k) Are you going to extend the use of them.

Piston Rods and Motion Bars.

Standard type.

a) Method of steel manufacture.
b) Maximum and minimum limits of tensile stress.
c) Minimum elongation per cent on 3 inches.
d) Carbon per cent.
e) Other special elements and percentage of each present.
f) Treatment after forging.

Experimental type.

g) Have you any piston rods or motion bars of higher tensile strength running experimentally.
h) If so what number.
i) What is the tensile strength.
j) Elongation per cent on 3 inches.

k) Carbon per cent.
l) Other special elements and per cent of each present.
m) Treatment after forging.
n) What per cent saving weight have you been able to effect by substituting this special steel.
o) What is the difference in wear between the ordinary and special type.
p) What is the percentage increase in price.
q) Are you going to extend the use of this type.

Connecting and Coupling Rods.

Standard type.

a) Method of steel manufacture.
b) Maximum and minimum limits of tensile stress.
c) Minimum elongation on 3 inches.
d) Carbon per cent.
e) Other special elements and percentage of each present.
f) Treatment after forging.

Experimental type.

g) Have you got any connecting or coupling rods of higher tensile strength running experimentally.
h) If so what number.
i) What is the tensile strength.
j) Elongation per cent on 3 inches.
k) Other special elements and percentage of each present.
l) Treatment after forging.
m) What percentage saving in weight have you been able to effect by substituting this special steel.
n) What is the percentage increase, in price.
o) Are you going to extend the use of this type.

Other motion arrangements.

a) Do you use steel of higher tensile stress than 32 tons per square inch for any other motion work.
b) If so, what is the tensile strength.
c) Elongation per cent on 3 inches.
d) What is the carbon per cent.
e) Other special elements and percentage of each present.
f) Give special parts for which this class of steel is used.
g) Give particulars of results obtained in service in relation to the material used previously.
h) What percentage saving in weight have you been able to effect by substituting this special steel.
i) What is the percentage increase in price.
j) Are you going to extend the use of this.

*

Steel castings.

a) Do you use steel castings of a tensile stress of 35 tons and above for any parts of locomotives, carriages and wagons.
b) If so, what is the tensile strength.
c) Elongation per cent on 3 inches.
d) Carbon percentage.
e) Other special elements and percentage of each present.
f) Give a list of the parts for which you use these castings, saying in each case of what they were made previously.
g) What was the object in making the change.
h) What advantages have you obtained in service owing to the use of this material.
i) What is the percentage increase in price.
j) Are you going to extend the use of this.

Laminated springs for locomotives and tenders, for carriages and for wagons.

Standard type.

a) Method of manufacture.
b) Carbon percentage . . . . . { Top plates. / Other plates.
c) Special elements and percentage of each present. . . . { Top plates. / Other plates.
d) What test do you impose on the steel prior to acceptance.
e) What test do you impose on the finished springs prior to acceptance.
f) What method of tempering, etc., do you employ or specify.
g) What stress in tons per square inch (calculated from the stationary load) do you work your springs at.

Experimental type.

h) Have you got any springs of a special class of steel running experimentally.
i) If so, what number.
j) Carbon percentage. . . . . { Top plates. / Other plates.
k) Other special elements and percentage of each present. . . { Top plates. / Other plates.
l) What method of tempering is employed.
m) What per cent increase of stress do you allow with these springs made of special steel.
n) Can you give the mileage (or life) of these springs in relation to those of your standard type when employed on similar work.
o) What is the percentage increased price per spring.
p) Are you going to extend the use of this type.

Volute and helical springs for locomotives and tenders, for carriages and for wagons.

Standard type.

a) Method of steel manufacture.
b) Carbon percentage.

c) Other special elements and percentage of each present.
d) What test do you impose on the steel prior to acceptance.
e) What test do you impose on the finished springs prior to acceptance.
f) What method of tempering do you employ or specify.
g) What stress in tons per square inch (calculated from the stationary load) do you work your springs at.

Experimental type.

h) Have you got any springs of a special class of steel running experimentally.
i) If so, what number.
j) Carbon percentage.
k) Other special elements and percentage of each present.
l) What method of tempering is employed.
m) What percentage increase of stress do you allow with these springs made of special steel.
n) Can you give the mileage (or life) of these springs in relation to your standard type when employed on similar work.
o) What is the percentage increased price per spring.
p) Are you going to extend the use of this type.

Drawgear and drawhooks.

a) Do you use steel of higher tensile strength than 32 tons per square inch for drawhooks.
b) If so, what is the tensile strength.
c) What is the carbon percentage.
d) Other special elements and percentage of each present.
e) What is the breaking strength of these hooks and what load causes deformation.
f) What was the breaking strength of old type hooks of similar section and what load caused deformation.
g) What percentage increase of life do you get from these special steel hooks.
h) What is the percentage increase in price per hook.
i) If these hooks are of lighter section than the old type what is the percentage saving in weight.
j) Are you going to extend the use of this type of drawhook.

Three link couplings.

a) Do you use steel of higher tensile strength than 32 tons per square inch for three link couplings.
b) If so, how are they manufactured.
c) What is the tensile strength.
d) What is the carbon percentage.
e) Other special elements and percentage of each present.
f) What is the breaking strength of these couplings and what load deforms them to such an extent that they will not fit the drawhook.
g) Of what were they made previously.

h) What was the breaking strength of the old type of similar section and what load deformed them to such an extent that they would not fit the drawhook.
i) What percentage increase of life do you get from these special steel couplings.
j) What is the percentage increase in price per coupling.
k) If these couplings are of a lighter section than the old type, what is the percentage saving in weight.
l) Are you going to extend the use of this type of coupling.

Screw couplings.

a) Do you use steel of higher tensile strength than 32 tons per square inch for any part of screw couplings.
b) If so, what parts are made of this special steel.
c) What is the tensile strength.
d) What is the carbon percentage.
e) Other special elements and percentage of each present.
f) What is the breaking strength of these couplings, and at what load is the screw unworkable.
g) Of what were they made previously.
h) What was the breaking strength of the old type of similar section and at what load was the screw unworkable.
i) What percentage increase of life do you get from these special steel couplings.
j) What is the percentage increase in price per coupling.
k) If these couplings are of a lighter section than the old type what is the percentage saving in weight.
l) Are you going to extend the use of this type of coupling.

[621 .131.2 & 625 .246]

REPORT N° 5

(all countries except America)

By Ernest SZLABEY,

ASSISTANT MANAGER OF THE LOCOMOTIVE AND ROLLING STOCK DEPARTMENT OF THE HUNGARIAN STATE RAILWAY.

I. — The use of steel in the construction of locomotives and rolling-stock.

In drawing up the list of questions which was sent to the different railway administrations, it was assumed that tires, axles, springs, draw and buffing gear, engine and boiler, were included among those parts which were to be considered and examined in connexion with subject V, littera *B*. The different railway administrations were consequently only requested to supply information about any other parts of the locomotives and rolling stock, which were made of steel.

In a very few cases, the answers sent also contained information about the parts excluded; this has accordingly not been dealt with in this report.

The list of the railway administrations adherent to the Congress, who have sent answers on this subject, and the different countries to which they respectively belong, are given in the following table.

Thus of the two hundred and fifty railway administrations (excluding America) who belong to the International Railway Congress Association, sixty-nine have sent answers to the list of questions; fourteen of these have however stated, that they do not use steel for such purposes.

The answers which have been received show that points of view have differed, and that the answers have been influenced by the different names used in different

Number.	COUNTRY.	Number of administrations adherent to the Congress.	Number of administrations who have answered the question.		
			In the affirmative.	In the negative.	Total.
1	Germany	7	5	2	7
2	Austria	9	4	2	6
3	Hungary	6	1	2	3
4	Belgium	12	1	...	1
5	Bulgaria	1	1	...	1
6	China	2	...	..	...
7	Congo	1	...	...	...
8	Denmark	4	1	...	1
9	Egypt	1	..	...	...
10	Spain	11	2	1	3
11	France, Algiers, Tunis and Colonies	37	7	...	7
12	Great Britain and Ireland, India and Colonies	60	23	3	26
13	Greece	5	...	...	...
14	Italy	34	1	..	1
15	Luxemburg	1	1	..	1
16	Norway	2	1	...	1
17	Holland and Colonies	11	2	..	2
18	Portugal and Colonies	5	...	...	...
19	Roumania	1	...	..	...
20	Russia	16	2	...	2
21	Servia	1	1	...	1
22	Sweden	8	1	1	2
23	Switzerland	11	1	2	3
24	Turkey	4	...	1	1
	Total.	250	55	14	69

countries, and especially by the lack of precision in the meaning of the term, "steel". Thus several administrations, give figures for the properties of the

" steel " used, which show that the material in question can hardly be described as steel at all, but should, more correctly, be called ingot iron.

Consequently, it is also difficult, in cases where administrations simply state that steel is used, without giving any particulars, to be quite certain that the parts in question are actually made of steel, and hence it is impossible to draw any conclusions to which no objection can be raised.

In what follows, we shall therefore only consider those parts more in detail, about which we have definite information as to their quality, and shall only consider those as made of " steel ", which are made of metal having an ultimate tensile strength of at least 44 kilograms per square millimetre (62,580 lb. per square inch).

The kinds of steel used in the different countries differ widely both in quality and in name; they can however be grouped into two chief classes :

1° Forged or rolled Siemens-Martin steel;

2° Steel castings made of Martin steel.

The former is generally used for parts which are subjected to much fatigue and wear and tear, and which owing to simplicity of form can be easily and cheaply produced by forging methods, for instance brake-shafts, brake-shaft bearings, pins and bushes, cranks and crank pins, coupling and connecting rods, valve rods, piston heads, reversing screws, sundry keys, frame plates, etc., of locomotives; and bogie pivots, swing links and hangers, brake shafts, sundry keys, etc., of passenger carriages and goods wagons.

Steel castings made of Martin steel are as a rule used for those parts, which are also subjected to much fatigue and much wear and tear, but which are of more complicated shape, so that it would be either too costly to produce them by forging methods, or in many cases even impossible.

Steel castings are consequently extensively used for the following : axle-boxes, hornplates, hornblocks, bevel wheels, cranked brake levers, brake-shaft brackets, brake-shaft bearings, steam cylinders, some valve-chest and cylinder covers, crossheads, slide bars and their supports, valve links, frame supporting reversing gear, steam connections, roof bars, superheater caps, buffer boxes, wheel centres, cross framing, spring hangers, centre-pin sockets of bogies, bogie frames, stuffing boxes, sundry supports and brackets, etc., of locomotives; axle-boxes, axle-guards, bogie frames, swing links, centre-pin sockets of bogies, body queen posts, brake-shaft bearings, brake-rod and brake-lever bearings, cranked brake levers, hangers, door hooks and shackles, door rollers, sundry fittings, buffer boxes, wheel centres and wheel disks, lamp brackets, brackets for supporting gangways, spring buckles, stanchion pockets, etc., of passenger carriages and goods wagons.

Table A contains a summary of the information sent by the different administrations on the subject of the quality coefficients of the steel used for the more important parts, such as coupling and connecting rods, piston and valve rods, cranks and crank pins, and locomotive frames; also of the steel castings used for wheel centres, axle-boxes and hornblocks. In addition, all the administrations attach

great importance to uniform structure and homogeneity of the material, and in addition to tensile tests, other tests are also specified, such as bending tests, hardness tests and impact tests; in such cases a maximum phosphorus content is also specified.

In the case of steel castings, it is specified that they are to be annealed, in order to remove any strain due to the casting operation; it is also specified that the material should be malleable and as little porous as possible.

Table A shows that steel having an ultimate tensile strength of over 44 kilograms per square millimetre (62,580 lb. per square inch) is used for :

a) Connecting and coupling rods, in Germany, Great Britain and Switzerland;

b) Piston rods and valve rods, occasionally, in Germany, Great Britain and Switzerland;

c) Cranks and crank pins, in Germany and South Africa;

d) Locomotive frames in Spain, Great Britain, South Africa, Italy and Sweden.

The steel castings used for wheel centres have an ultimate tensile strength, in the following countries, of :

Germany. . : .	37 to 45	kilog.	per sq.	millim.	(52,625 to 64,000	lb.	per sq.	inch).
Austria	40 to 60	—	—	—	(56,890 to 85,340	—	—	).
Hungary. . . .	40 to 50	—	—	—	(56,890 to 71,115	—	—	).
Belgium. . . .	40	—	—	—	(56,890	—	—	).
Spain.	38 to 45	—	—	—	(54,045 to 64,000	—	—	).
France	40 to 45	—	—	—	(56,890 to 64,000	—	—	).
Great Britain . .	41 to 53	—	—	—	(58,314 to 75,380	—	—	).
Luxemburg. . .	40	—	—	—	(56,890	—	—	).
Norway. . . .	37 to 44	—	—	—	(52,625 to 62,580	—	—	).
Holland. . . .	42 to 55	—	—	—	(59,735 to 78,225	—	—	).
Russia	45 to 55	—	—	—	(64,000 to 78,225	—	—	).

The steel castings used for axle-boxes and hornplates have as a rule a greater ultimate tensile strength than in the case of wheel centres.

It is worth notice that no administration has stated that it uses steel castings for locomotive frames; it consequently seems that the practice, much in favour in America, of making locomotive frames of steel castings, is not adopted in any other country. Steel castings are however used in some cases for bogie frames, in Denmark, Algiers, India and Sweden.

The qualities which make steel castings specially suitable for replacing wrought iron and cast iron, are their greater ultimate tensile strength, their greater resistance to wear and tear, and their longer life. In addition, there is the fact that wrought iron is becoming rarer and rarer, and is hardly made any more, so that it is continually becoming more difficult to procure it. On the other hand, we may consider that the difficulties of producing compact steel castings, free from blowholes, have by now been overcome by the continuous progress made in metallurgical science.

It is hence intelligible that steel castings are not only a very good substitute for cast iron, but also for wrought iron; and, particularly when articles of complicated

shape are wanted in large quantities, steel castings are materially superior to wrought iron from the economic point of view.

A few of the railway administrations have been extensively using forged steel and steel castings for twenty-five to thirty years, others only for three to five years; this is no doubt partly due to the state of development of the iron industry in the country concerned, partly also to the work the locomotives and rolling stock have to do, and this has materially increased of late.

The results which these two varieties of steel have given in actual practice, are excellent, according to the nearly unanimous verdict of all the administrations; the two materials gave every satisfaction, in the case of both locomotives and rolling stock, as regards safety of operation, life and need of repair, and owing to the low cost of maintenance, they give very good results from the economic point of view.

Most of the administrations state that in consequence of these favourable results, all those parts which have hitherto been made of forged steel or of steel castings, will also in future be made of these same materials; many administrations have the intention to use steel castings much more extensively, more especially as a substitute for grey cast iron, and for wrought-iron parts of complicated shape.

Besides the above advantages, there is the possibility of reducing the weight of the parts by reducing the dimensions and altering the shape; as against all these advantages, only a few minor disadvantages are mentioned in a few cases.

Thus some administrations found that some lots of wheel centres showed cracks, on account of insufficient annealing, others had cases of fractures of wheel disks which were steel castings; the Dutch State Railway no longer makes spring hangers and bogie-frame connexions of steel castings, as fractures occurred in some cases.

Then also the prime cost of steel castings is higher, and they are more difficult and consequently more costly to machine, than cast iron; but these disadvantages are more than counterbalanced by the longer life, lower cost of maintenance and greater safety of the steel castings.

CONCLUSIONS.

Steel having an ultimate tensile strength of over 44 kilograms per square millimetre (62,850 lb. per square inch) is used, instead of the wrought iron formerly used everywhere, only by a few of the administrations, only for a few of the locomotive parts in question, for instance for connecting and coupling rods, piston and valve rods, cranks and crank pins, and locomotive frames. As general substitute for wrought iron, mild steel or ingot iron is used, having an ultimate tensile strength of 33 to 44 kilograms per square millimetre (46,935 to 62,580 lb. per square inch).

Steel castings are in many cases used as a substitute for wrought iron in the case of parts which are difficult to make and are of complicated shape. Steel castings are very generally used as a substitute for cast iron in the case of parts, which are subjected to much fatigue and wear and tear, and more exposed to damage; their use in such cases results in increased security.

II. — Carriages and wagons made entirely of steel or iron.

The list of the railway administrations, adherent to the Congress, who have sent answers on this subject, and the different countries they respectively belong to, are given in the following table.

The above table shows that only a comparatively-small proportion of the railway administrations, *i. e.* about one sixth, sent more or less detailed answers, while the great majority of the administrations adherent to the International Railway Congress Association either did not answer at all (one hundred and eighty-four administrations), or only answered in the negative (twenty-nine administrations).

Before we deal with the subject, we therefore have to remark that although the summary given below is based on the information supplied, chiefly by important railways, yet it can give no comprehensive view of the subject in question, as regards railways outside America; hence it is quite possible that the conclusions arrived at will require correction at the hands of those administrations which, owing to the circumstances mentioned, had to be left out of consideration.

The many-sidedness and the comprehensiveness of the information received, made it advisable to summarize it in a table (see table B), and this table is accordingly annexed to this report.

It also seemed advisable to select, from the drawings and sketches sent by the different administrations, the most characteristic types of the rolling stock, and annex them to this report (see figs. 1 to 79).

Finally it has to be observed that the material described as " steel " by the majority of the administrations is not so much a material having special properties, such as a great ultimate tensile strength, but a material used very generally for rolling sections, bars, plate and sheet. It will consequently be described in what follows simply as " iron ".

It has to be recorded that according to the unanimous report of all the railway administrations, no passengers carriage made " *wholly of iron* " has as yet been constructed and used on any railway in the countries outside America.

If we take into consideration, that the underframes and bogies of modern passenger carriages and luggage vans are made nearly exclusively of iron, instead of wood, or at least of iron and wood together, it seems remarkable that iron has as yet found no application for the frame of the body, for the lining or fitting inside the body, for doors, etc.; any experiments made in this direction have not been followed up.

This remarkable state of affairs is probably due to the fact that, on the one hand, great difficulties turned up in the experimental applications, that on the other hand, as regards passenger carriages, questions of strength and of durabibity are not paramount, but that other conditions have also to be satisfied, such as any existing aesthetic considerations, protection against heat and cold, greater elasticity and consequently greater safety against violent damage, etc.

Number.	COUNTRY.	Number of administrations adherent to the Congress.	Number of administrations who have answered the question.		
			In the affirmative.	In the negative.	Total.
1	Germany	7	4	3	7
2	Austria	9	1	5	6
3	Hungary	6	1	2	3
4	Belgium	12	1	...	1
5	Bulgaria	1	.	1	1
6	China	2	..	..	.
7	Congo	1		..	...
8	Denmark	4	.	1	1
9	Egypt	1	..	...	...
10	Spain	11	1	2	3
11	France, Algiers, Tunis and Colonies	37	6	2	8
12	Great Britain, and Ireland, India and Colonies	60	18	5	23
13	Greece	5	...	.	...
14	Italy	34	1	..	1
15	Luxemburg	1	...	1	1
16	Norway	2	...	...	...
17	Holland and Colonies	11	...	2	2
18	Portugal and Colonies	5	...	..	.
19	Roumania	1	...	...	..
20	Russia	16	1	1	2
21	Servia	1	1	...	1
22	Sweden	8	1	1	2
23	Switzerland	11	1	2	3
24	Turkey	4	...	1	1
	Total.	250	37	29	66

An exception is however to be found in the case of some underground railways, where iron is also used for the whole frame of the body. In these cases the

loading gauge is limited, and the available cross-section so much reduced, that it is absolutely necessary to reduce dimensions as much as possible; the unusual shape of the cross-section available on such underground railways, and the consequent shape of the carriages, make it impossible to use any material except iron; moreover, it was necessary to do as far as possible without combustible matter.

As yet only goods wagons have been built wholly of iron. Particulars are given in table C about the number of such goods wagons, their distribution in the different countries, their type and their tonnage.

It cannot be said that the number of goods wagons built wholly of iron, or having only a wooden floor, is at all considerable. Our returns, up to the end of 1908, include altogether 94,850 goods wagons, of which 29,505 (31 per cent in round figures) were in Europe and 65,345 (69 per cent in round figures) in India, South Africa and Australia.

It is a remarkable fact that in Europe, a comparatively-small percentage of the rolling stock is made wholly of iron, and that in Europe only open wagons are made in this way, apart from the tank trucks and gas trucks and power trucks of some of the British railways, while in other continents, in India, South Africa and Australia, iron is exclusively used for nearly the whole of the goods stock.

This state of affairs is probably due to the fact that the climatic conditions and the scarcity of timber in these countries, which are chiefly tropical, make it inadvisable or expensive to use wooden bodies; but it also depends on the fact that the rolling stock of these railways is largely manufactured in the mother country or in other countries, and is shipped over taken in pieces, which are put together on the spot; and iron is more suitable for this purpose than wood.

A table C shows, the goods wagons built wholly of iron can be classified into the following groups :

1° Covered goods wagons, for general purposes (figs. 44, 46, 47, 50, 51, 56 to 58, 64, 65);

2° Special wagons for carrying powder and explosives, such as are used in Great Britain;

3° Goods wagons for carrying goods in bulk, such as coal, ore, slag, lime, ballast, stone, beetroot, coke, timber, etc.; most of the wagons built wholly of iron belong to this class (figs. 2, 4, 8, 9, 15, 17, 23, 25, 28, 30, 33 to 37, 39, 40, 42, 45, 48, 49, 52, 54, 55, 59 to 63, 66, 68, 69, 71 to 77, 79);

4° Goods wagons for the carriage of articles of exceptional weight or size, such as heavy guns, castings, armour plate, rails, girders, plates, etc. These consist of flat or low-sided trucks, either with a flat floor, or with one sunk in the middle, with the longitudinal frame cranked (figs. 6, 7, 13, 20, 24, 26, 27, 29, 31, 32, 43, 70);

5° Goods wagons for carrying manure, copperas, produce which has a bad smell, etc. These are high-sided wagons, which can be closed by flaps which can be swung open (figs 1, 16);

6° Goods wagons for conveying liquids (mineral oils, tar, spirit, benzene, sulphuric acid, water, illuminating gas); they are generally equipped with a cylindrical tank to hold the liquid (figs. 14, 19).

As regards the wagons in group 3, it has to be noted that they are in many cases constructed so as to be self-discharging, that is to say, that the goods loaded in them are unloaded automatically by opening traps in the floor (figs. 3, 5, 10, 11, 12, 18, 21, 22, 38, 41, 53, 78).

Although the railway administrations of some countries, including that in which there are the greatest number of iron wagons (India), do not give a detailed classification of their goods wagons according to number of axles and tonnage, yet table C shows us that the goods wagons up till now wholly built of iron are most frequently wagons with two axles, to carry 10 to 20 tons; the covered goods and the open wagons with flat and sunk floor are also constructed in considerable numbers with four axles and to carry 20 to 50 tons.

The coal wagons equipped with self-discharging devices are comparatively few in number; they have four axles and carry from 27 to 40 tons. The six-axled Talbot coal wagons of the Hungarian State Railway were given the six axles not on account of large tonnage, but because the track on the local lines on which they circulate is not equal to axle-loads of over 10 tons.

The flat trucks have in most cases four axles, even when they are for lighter loads such as 15 tons, and they built for loads of up to 50 tons; there are however also 20-ton wagons with three axles and 6-ton wagons with two axles.

Among special wagon we may mention 20-ton ore wagons with two axles, and 35-ton ore wagons with three and four axles, and three-axled tank trucks; an ordinance truck for carrying 70 tons was given eight axles.

As regards the design of the wagons, it may be stated generally that the frame of the body is made of rolled sections, fixed to the underframe of the wagon (whether with brakes or without); and the walls, roof and floor are made of iron or steel plate, which is either flat or is stiffened by being pressed into shape, together with stampings.

A few of the railway administrations however found it advisable, even in the case of wagons otherwise built wholly of iron, to put in a wooden flooring instead of one made of iron plate.

Many administrations have the ends, and some cases the sides, of the wagons, both high-sided and low-sided, fitted with drop doors, or made so that they can be taken off.

The use of goods wagons built wholly of iron dates back, on the European lines, to 1866; but their use on a more extended scale and by a number of railways began about 1880. A few of the European railways, for instance in France, Russia and England, have only introduced such wagons very recently and that only experimentally.

The wagons originally built, with very few exceptions, had two axles and a tonnage of 10 to 20 tons.

The construction of open goods wagons for carrying goods in bulk, of a larger tonnage, such as 20 to 40 tons, and of self-discharging wagons, only dates back to the beginning of the present century.

On other continents, however, the use of wagons built wholly of iron dates back to 1883; these wagons either had two axles, and took 10 to 20 tons, or, in many cases, had four axles (bogie wagons), and took 25 to 43 tons.

Further particulars are given in table B.

The reasons which led the railway administrations to use iron, exclusively, instead of wood, not only for the underframe and the running gear of the goods wagons, but also for the body, were varied. On the one hand, there was the desire to use for special classes of goods the most suitable wagons, or the only kinds of wagon which were suitable, such as the special wagons used for gunpowder, gas, manure and the coal wagons and tank trucks; then also there was the desire to increase the tonnage but reduce the tare, to simplify the design of the wagon and to make it stronger and increase its life. Finally, there are certain types of wagons, for instance the self-discharging wagons, or the wagons for carrying very heavy articles, which can only be made of iron.

As table B and figures 1 to 79 show, some of the railway administrations succeeded in obtaining a remarkably-low tare as compared with the tonnage. The information received does not however give any reliable information whether wagons built wholly of iron are lighter or heavier, for an equal tonnage, than goods wagons of the same type built of wood or of wood and iron; chiefly because the administrations, as a rule, do not possess wagons of the same types built of the latter materials; moreover, the information supplied shows that some administrations have wood and iron wagons which are heavier than the iron wagons, while other administrations have them lighter.

The same applies to the cost price of the wagons, which is much affected by the state of the market at the time of purchase, the place at which they were built, etc., and which was sometimes higher, and sometimes lower, in the case of iron wagons than in that of wagons built of both iron and wood.

As regards the tare and the cost, it may in any case be observed that those administrations who attach greater importance to greater durability and absence of need of repairing the wagons, and who consequently have the different constituent parts made stronger, have wagons which are heavier and accordingly cost more; a strong influence is also exercised by the varying design of the wagons (for instance, self-discharging wagons), their equipment with hand or with automatic brakes, the stiffening of the underframe when a very great tonnage is required, etc.

The tare is also materially affected by the selection of the plate used for the walls and floor of the body, or for the tanks; the thickness of the former varies between 4 and 8 millimetres (between $^5/_{32}$ and $^5/_{16}$ inch), and that of the tanks between 8 and 12 millimetres (between $^5/_{16}$ and $^{15}/_{32}$ inch). Special attention has however to be drawn to the fact that the use of pressed embossed plate and the replacement of rolled sections and forged parts by pressed plate girders and pressed parts have a very favourable influence on the reduction of the tare, as the thickness of the walls and the other dimensions can be very appreciably reduced for the same or even greater strength and stiffness.

The results obtained up to the present have led a few administrations to recognize unreservedly that the exclusive use of iron for the construction of goods wagons makes it possible to increase the tonnage materially, and is also attended with so many other advantages, that it

appears desirable to extend this practice. Some of the railway administrations mention, among such advantages, more especially the greater resistance in case of collision or other violent treatment, the greater safety of working, the fewer repairs required, the longer life and the greater security as regards fire risks. In addition there is the fact, that wagons with wooden bodies are very unsuitable for certain classes of goods, for instance liquids, manure, slag, lime, etc., and that the self-discharging coal wagons lately introduced, can only be constructed of iron.

As against these very favourable opinions, there are others which are less favourable. Some of the railways, for instance, the Prussian State Railway, the Bavarian State Railway, the Hungarian State Railway, the Russian Catherine II Railway, the Midland Railway, the Great Central Railway, etc., state, among the disadvantages of iron wagons, that the cost of repair is very high, that the repairs take a long time and are difficult to carry out, and especially that the walls and floor soon become rusted through in a damp climate. Most of the European railway administrations therefore, find it indispensable, in order to prevent the rusting of the plates, to pay particular attention to the repeated coating of the walls, both inside and outside, with red-lead paints and tar, and to have a wooden flooring, not one made of iron plate. It is also advisable to round off the lower corners of the body, so as to avoid the presence of sharp angles.

The North Eastern Railway moreover, does not consider the exclusive use of iron suitable for wagons of those types which are to be used for the carriage of salt or of those bulk goods which when damp exercise a corrosive action on the iron; it also considers it unsuitable, in the case of covered goods wagons, if the goods carried are to be protected against temperature variations.

Taking into consideration however the very short time that iron wagons generally, or only certain types of them, have been in use, a number of administrations are as yet unable to express any definite opinion as to the merits and demerits of these wagons, and consequently as to their suitability for railway work.

In accordance with the results obtained, most of the railways intend to continue to make wagons of different types of the same materials as at present, either wholly of iron, or of iron with a wooden flooring. Other railways however, for instance the Prussian State Railway, the French Northern Railway, the Hungarian State Railway, the Paris-Lyons-Mediterranean Railway, intend in future only to build the wagons made wholly of iron in those cases, in which other materials are excluded, for instance, tank trucks, manure wagons, etc., and in those cases where the design makes this absolutely necessary, for instance, wagons to take very heavy goods, self-discharging coal wagons; and these railways think it advisable, as regards open high-sided and low-sided wagons, to make only the frame of the body of iron, but the walls and floor of wood.

On the other hand, the results obtained by the railway administrations on the other continents have been such, that they intend, when they require new rolling stock, to have the goods wagons of the

types they are at present using again built wholly of iron.

Taking into consideration the very different requirements the railways of the world have to meet, in consequence of the variations in the industrial, climatic and other conditions, and in the geographical positions of the different countries, it is not possible to lay down general principles concerning the most suitable design of the goods wagons and the best material for their construction.

Nevertheless, all the railway administrations show a tendency, on the one hand, to design and obtain special wagons which are as suitable as possible for given classes of traffic, or the other hand to increase the tonnage materially, but to reduce the tare as much as is practicable. This is especially the case as regards bulk goods, particularly coal and ore; in order to reduce the cost of carriage and of handling these goods, iron self-discharging wagons were introduced and the tonnage increased up to 40 tons, and this practice is being continually extended; the results obtained so far have been exceedingly satisfactory.

A characteristic feature of modern wagons is the greater tonnage and the use of self-discharging wagons; this however makes it necessary that not only the underframe and the running gear, but also the body, are wholly made of iron. In order to satisfy the second important condition, namely the reduction of the tare without reducing the strength and the durability, the rolled sections, flat plates and expensive forgings are in the modern designs replaced by pressed plates and frames and steel castings, to a continually-increasing extent; these means make it possible to reduce the cross-sections and the dimensions of the parts, while increasing their strength and their durability. Care however must be taken to prevent corrosion, and frequent coats of paint must be applied for the purpose.

The results obtained and the information received lead to the following conclusions :

CONCLUSIONS.

1° Passenger carriages made wholly of steel and iron have up till now not been used at all, or only in some very special cases ;

2° Goods wagons made wholly of steel and iron are only used on European railways to a rather small extent; on railways in colonies in other continents, they are however used extensively or nearly exclusively;

3° Steel and iron are suitable not only for the underframe and the running gear, but also for the whole body of those open goods wagons, which are to have a large tonnage and as low a tare as possible, which are accordingly intended for the carriage of very large or very heavy articles, of liquids, of manure, of lime, and also and especially of bulk goods, such as coal, ore, ballast, beetroots, etc., and finally for that of those wagons of special design which are intended to discharge goods in bulk, particularly coal, automatically, and which are known as self-discharging wagons.

On the other hand, in Europe, the exclusive use of steel and iron for making bodies is only usual in the case of those covered goods wagons which are specially for the carriages of dangerous and explosive goods;

4° It is advisable, even in the case of the open and covered goods wagons built wholly of steel and iron, to use wood for the flooring instead of metal plates, and to round the bottom corners;

5° Replacing the rolled girders, plates and sections and the forged parts, by pressed girders, plates and parts and by steel castings, makes it possible to reduce the tare and increase the durability and strength of the wagons;

6° In order to prevent corrosion, care must be taken to provide for repeated renewal of the paint.

Table A.

PART.		Germany.				
		Baden State Railway.	Bavarian State Railway.	Prussian-Hessian State Railway.	Saxon State Railway.	Wurtem Stat Railw
						Forge
Connecting and coupling rods.	Material	...	...	Martin-Thomas or Bessemer steel.	...	Martin s
	Ultimate tensile strength, in kilog. per sq. millim.	...	...	50-60	...	50
	Elongation, per cent	...	...	20	...	20
	Contraction of area, per cent	...	...	...	...	30
Piston and valve rods.	Material	...	...	...	...	Crucible
	Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	...	60
	Elongation, per cent	...	...	...	...	20
	Contraction of area, per cent	...	...	...	...	35
Cranks and crank pins.	Material	...	...	Martin-Thomas or Bessemer steel.	...	...
	Ultimate tensile strength, in kilog. per sq. millim.	...	...	50-60	...	...
	Elongation, per cent	...	...	20	...	...
	Contraction of area, per cent	...	...	...	...	...
Longitudinal frame.	Material	...	...	...	...	...
	Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	...	...
	Elongation, per cent	...	...	...	...	...
	Contraction of area, per cent	...	...	...	...	...
						Steel ca
Whee centres.	Material	Ingot iron.	...	Ingot iron.	Steel.	...
	Ultimate tensile strength, in kilog. per sq. millim.	37-44	...	37-44	38-45	...
	Elongation, per cent	20	...	20	20	...
	Contraction of area, per cent	...	...	...	...	...
Axle-boxes and guides.	Material	Ingot iron.	Ingot iron.	Ingot iron.	Steel.	...
	Ultimate tensile strength, in kilog. per sq. millim.	50-60	40-50	37-44	38-45	...
	Elongation, per cent	12	20	20	20	...
	Contraction of area, per cent	...	...	...	...	...

Table A.

Austria.				*Hungary*	*Belgium*	*Denmark*	*Spain*		*France*	
Austrian State Railway	Aussig-Teplitz Railway.	Austrian North Western Railway.	Austrian Southern Railway.	Hungarian State Railway.	Belgian State Railway.	Danish State Railway.	Anda-lusian Railway.	Spanish Northern Railway.	French Eastern Railway.	French State Railway.
lled parts.										
...	...	...	...	Martin ingot iron.	...	...	...	...	...	...
...	...	.		40-50	. .	..	. .	.	...	...
...	. .	.	.	...		.	. .	.	. .	...
...	. .			40	...	...	. .	.	. .	. .
...	. .			. .	.		. .			...
..				.	.		.	.		...
...				.	.		.	.	.	...
...				...			..	. .	..	...
...	...			Ingot iron.	.	.	..	.	.	Forgeable steel.
...	.			35-46	...	.			..	40
...	.	.		20	.	. .	. .		. .	20
...	. .		...	50	...	...	...	...	...	...
...	.	...	Martin ingot iron.	Martin-Siemens ingot iron.	Ingot iron.	Weldable mild steel.	Ingot iron.	Bessemer steel.	Steel.	Steel.
...	. .		38-43	33-40	35	37-44	38-42	45-50	40	40
...	.	..	25	...	28	20	26-38	22-18	25	25
...	...	...	45	50	...	...	...	...	...	..
Steel castings.										
Steel.	Steel.	Martin steel.	Steel.	Martin steel.	Steel.	. .	Steel.	.	Steel.	Steel.
45-60	50	50-60	40-50	40-50	40	. .	38-45	. .	40-45	40 or 45
18-12	12	15	15	15	15	. .	15-18	..	20-15	20 or 15
...	...	35	35	. .	...	...	...	.	. .	...
Steel.	Steel.	Steel.	Steel.	. .	Steel.	Steel.	Steel.	.	...	...
50	50	40-50	40-50		40	38-45	38-45	.	. .	..
12	12	15	15	.	15	20	15-18	...	. .	. .
...	...	...	35	...	...	...	...	...	...	...

Table A (*continued*).

PART.	France.				
	Midi Railway.	French Northern Railway.	Orleans Railway.	Paris-Lyons-Mediterranean Railway.	Caledonian Railway.
					Forged a
Connecting and coupling rods. — Material	...	...	...	...	...
Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	...	...
Elongation, per cent	...	...	...	...	...
Contraction of area, per cent	...	...	...	...	...
Piston and valve rods. — Material	...	...	...	...	...
Ultimate tensile strength, in kilog. per sq millim.	...	...	...	...	...
Elongation, per cent	...	...	...	...	...
Contraction of area, per cent	...	...	...	...	...
Cranks and crank pins. — Material	...	...	...	...	...
Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	...	...
Elongation, per cent	...	...	...	...	...
Contraction of area, per cent	...	...	...	...	...
Longitudinal frame. — Material	Martin steel.	Martin steel.	Martin steel.	Martin steel.	...
Ultimate tensile strength, in kilog. per sq. millim.	40	35	35	40	...
Elongation, per cent	25	28	28	25	...
Contraction of area, per cent	...	...	...	...	...
					St
Wheel centres. — Material	Steel.	Steel.	Steel.	Steel.	Steel.
Ultimate tensile strength, in kilog. per sq. millim.	40	45	40	40-45	41
Elongation, per cent	20	15	20	20-15	15 %, measure on 2 inches
Contraction of area, per cent	...	...	...	Steel.	..
Axle-boxes and guides. — Material	...	Steel.	...	45	...
Ultimate tensile strength, in kilog. per sq. millim.	...	45	...	15	...
Elongation, per cent	...	15	...	...	...
Contraction of area, per cent	...	...	...	...	...

Table A (*continued*).

Great Britain and Ireland.

Great Central Railway.	Great Eastern Railway.	Great Western Railway.	Lancashire & Yorkshire Railway.	Midland Railway.	North Eastern Railway.	South Eastern & Chatham Railway.	Furness Railway.	Great Southern & Western Railway.	Hull & Barnsley Railway.	London Tilbury & Southend Railway.
d parts.										
harden-le steel.	Forgeable acide steel.	...	...	...	...	...	...	...	...	Bessemer Steel.
11-47·5	39.5-47.5	...	...	...	...	...	...	...	...	58
% measur. 2 inches	25 % measur. on 8 inches.	...	...	...	...	...	...	...	...	20 % meas. on 2 inches
...	50-60	...	...	...	...	...	...	...	...	44
Siemens ace steel.	Forgeable steel.	...	...	...	Mild steel oil-hardened.	...	...	...	...	...
66-72	55-63	...	...	...	63-70·8	...	...	...	...	...
% measur. 2 inches.	25 % measur. on 3 inches.	...	...	...	20-15 meas. on 3 inches.	...	...	...	...	...
...	50	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	Pressed Swedish steel.
...	..	...	...	...	...	...	...	...	...	44-50
...	...	...	...	...	...	...	...	...	...	25 meas. on 2 in.
...	...	...	...	...	...	...	...	...	...	50
Steel.	Mild steel.	...	Martin-Siemens steel.	Martin-Siemens steel.	Mild steel.	...	...	...	Forgeable acid steel.	Martin-Siemens steel.
41-47	44-50	...	41-47	41-50	44-50	...	...	...	44-50	47
% measur. 10 inches.	20 % measur. on 8 inches.	...	20 % measur. on 8 inches.	22 % measur. on 8 inches.	22 % meas. on 8 inches.	...	...	...	20	25 % meas. on 2 inches.
...	50-60	...	...	...	...	...	...	...	...	54
ngs.										
Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.
44-50.5	41	41	44	44-53.5	41	41	41	44-47	44	41
4 measur. 2 inches.	15	15 % measur. on 3 inches.	20 % measur. on 2 inches.	20 % measur. on 2 inches.	15 % meas on 3 inches.	15 % meas. on 3 inches.	15 % meas. on 3 inches	25-20 meas. on 2 inches.	20	15
...	30-40	...	...	...	...	...	...	...	...	40
...	...	Steel.	...	Steel.	...	Steel.	...	...	...	Steel.
...	...	41	...	44-53.5	...	55	...	...	...	41
...	...	15 meas. on 3 inches.	...	20 meas. on 2 inches.	...	10 meas. on 3 in.	...	...	...	15
...	...	...	...	...	...	...	...	...	...	20

*

Table A *(continued).*

PART.	Empire of India and Colonies.				
	Taff Vale Railway.	Eastern Bengal Railway.	Oudh & Rohilkhand Railway.	Central South African Railway.	Tasmani Governme Railway.
Connecting and coupling rods.					Forged
Material	...	...	...	Martin-Siemens steel.	...
Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	42·5-49	...
Elongation, per cent	...	...	...	35 measured on 2 inches.	...
Contraction of area, per cent	...	...	...	...	...
Piston and valve rods.					
Material	...	...	...	Martin-Siemens steel.	...
Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	55-63	...
Elongation, per cent	...	...	...	25	...
Contraction of area, per cent	...	...	...	...	...
Cranks and crank pins.					
Material	...	...	...	Martin-Siemens steel.	...
Ultimate tensile strength, in kilog. per sq. millim.	...	...	...	47·25-55	...
Elongation, per cent	...	...	...	30 measured on 2 inches.	...
Contraction of area, per cent	...	...	...	..	...
Longitudinal frame.					
Material	Mild steel.	...	...	Martin-Siemens steel.	...
Ultimate tensile strength, in kilog. per sq. millim.	44-50	...	...	39·5-47·5	...
Elongation, per cent	20 measured on 8 inches.	...	...	20 measured on 2 inches.	...
Contraction of area, per cent	...	...	...	...	...
Wheel centres.					St
Material	...	Steel.	...	...	Steel.
Ultimate tensile strength, in kilog. per sq. millim.	...	41	...	...	42·5
Elongation, per cent	...	20 measured on 8 inches.	...	...	22
Contraction of area, par cent	...	...	...	..	30
Axle-boxes and guides.					
Material	...	...	Steel.	...	...
Ultimate tensile strength, in kilog. per sq. millim.	...	...	44	...	...
Elongation, per cent	...	...	40	...	...
Contraction of area, per cent	...	...	...	...	...

Table A (*continued*).

Italy.	*Luxemburg.*	*Norway.*	*Holland.*		*Russia.*	*Servia.*	*Sweden*	*Switzerland*
Italian State Railway.	Prinz-Heinrich Railway.	Norwegian State Railway.	Dutch State Railway.	Dutch Railway Company.	Polesia Railway.	Servian State Railway.	Swedish State Railway.	Swiss Federal Railway
ed parts.								
...	...	...	...	...	...	...	...	Soft Martin steel.
...	...	...	...	...	...	...	...	45
...	...	...	...	...	...	...	...	20
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	Medium-hard Martin steel.
...	...	...	...	...	...	...	...	55
...	...	...	...	...	...	...	...	20
...	...	...	...	...	...	...	...	. .
...	...	...	...	...	...	...	...	Ingot iron.
...	...	...	...	...	...	...	. .	36-42
...	...	...	...	...	...	...	...	25
...	...	...	...	...	...	...	...	...
lild steel.	...	...	Martin-Siemens steel.	Mild steel.	...	...	Extra-soft cast steel.	. .
45-50	...	...	36-45	36	...	...	48	...
20	...	...	20	...	...	...	17	...
...	...	...	...	50	...	...	...	...
ings.								
...	Steel.	Steel.	Steel.	...	Steel.	...	...	...
...	40	37-44	Basic : 42-44 Acid : 44-55	...	45-55	...	...	...
...	10-20	20	Basic : 20 Acid : 15	...	8	...	...	...
...	...	...	...	...	...	...	...	...
Steel.	...	...	Steel	...	Steel.	Steel.	...	. .
63-49	...	...	44-55	...	45-55	50-60	...	...
5 measured millimetres	...	...	15	...	8	20	...	...
...	...	...	...	. .	. .	...	...	...

Table B. **Goods wagons made**

1	2		4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wagons in use since.
	GERMANY				
1	Alsace-Lorraine State Railway. . .	←			Not
2	Baden State Railway	8	Manure wagons without brake	1	1897
		6	Slag wagons without brake	2	1908
		10	Self-discharging (Talbot with brake)	3	1902
3	Bavarian State Railway	749	Open wagons, high-sided, series O*d*	..	1870-1877
		510	Open wagons, high-sided, series OO*m* . . .	4	1906
		51	Coal wagons, self-discharging, series OO*t* . .	5	1903
		4	Crocodile, S. S. four axles	6	1879
		8	Crocodile, S. S. S., six axles	7	1904
4	Oldenburg State Railway.	...	...	...	...
5	Prussian-Hessian State Railway . .	8,855 (to end 1908).	Open goods wagons, for coal and coke. . . .	8	1903
				...	...
				9	...
6	Saxon State Railway	35	Self-discharging wagons	10	...
7	Wurtemberg State Railwayy . . .	←			Not
	AUSTRIA				
8	Austrian State Railway	157	Two-axled ore wagons.	11	1888
		1	Eight-axled gun truck.	13	1903
		46	Two-axled gas truck	...	...
		55	Three-axled tank truck	14	1884
		3,553	Tank trucks, privately-owned	...	...
		...	Self-discharging coal wagons, now being built.	12	1909

iron and steel.

Table B.

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Dimensions of body, inside. Width, in millimetres.	Dimensions of body, inside. Height, in millimetres.	Dimensions of body, inside. Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
one.							
To avoid the leakage of liquid.	Corners of floor are rounded off.	6,990	2,800	900	...	4·000	12·5
To prevent the charring of the sides.	Side-walls and end plates are embossed.	8,088	2,650	572	...	4·500	18·0
Made necessary by the design . .	Talbot design	6,490	2,920	...	20	3·500	17·0
To simplify the design and have greater strength.	...	6,550	2,500	800	...	...	10·0
...	Side-wall plates embossed.	6,500	3,060	1,700	...	3·400	20·0
...	Talbot design	11,490	2,680	1,645	...	9·000	38·0
. .	Cranked longitudinal girders. .	11,680	2,704	(Flat)	...	9·500	40·0
...	...	15,000	2,970	"	...	11·000	50·0
...	...	...	...	...	...	..	...
To have a low tare and as great a tonnage as possible. . . .	Side walls with one or two doors, ends fixed at the side of the brakesman's cabin, otherwise movable.	6,200	...	1,500	...	3·600	20·0
...	...	6,500	...	1,800	...	4·000	20·0 Coal or 15·0 coke.
...	...	7,200	...	1,800	...	4·000	
The design of the wagons makes it necessary to use iron.	Drop doors in floor, operated from outside.	6,490	2,940	from centre of buffers 2,050	19.4	3·500	15·0
one.							
Greater strength	Ore wagons, gun trucks, and tank trucks, are built partly of rolled sections, partly of rolled plate.	5,000	2,052	1,500	10	3·000	20
		14,500	2,900	"	...	...	70
		Three gas-holders 8,080	1,268 diameter	...	27	...	...
		Tank. 10,590	1,850 diameter	...	28	7·500	23·81
		...	...	...	...	...	...
Smaller tare, by the use of pressed parts	Pressed parts used exclusively.	6,100	3,000	2,255	27	4·900	20

Table B (*continued*). **Cools wagons made wi**

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost p of these wago to cost price of wag of similar type m of other materi
	GERMANY.						
1	Alsace-Lorraine State Railway. . .	←					N
2	Baden State Railway	...	7·500	Can not be given, as there are no similar types made of wood.	Have proved very suitable for manure, slag, ballast and coal.	3,000	Can not be giv
		...	8·900			4,537	
		10·000	...	...		6,250	
3	Bavarian State Railway	6·800	...	...	Suitable for the carriage of stone, coal, long and heavy articles.	...	...
		7·800	...	...		...	Cost price 9 cent higher t that of woo wagons.
		17·770	...	...		...	
		...	13·950	...		..	
		...	28·770	...		...	
4	Oldenburg State Railway	...	...	...	...	. .	...
5	Prussian-Hessian State Railway . .	...	8·450	Approximately the same tare as wagons of the same dimensions with iron underframe and wooden body.	No opinion can yet be expressed as the observations are not yet concluded.	5,000 to 5,625	Iron wagons w brake cost ab 30 per cent, wi out brake ab 35 per cent more than similar w gons with wo den bodies.
		...	8·250			...	
		9·250	8·250			...	
6	Saxon State Railway	10·250	9·400	Such wagons made of other materials are not in existence.	For the carriage of coal, slag, and sand and goods in bulk.	5,375 to 6,500	...
7	Wurtemberg State Railway	←					No
	AUSTRIA.						
8	Austrian State Railway	7·700	...	...	For carrying liquids, ore, guns, gas and coal; self-discharging in the last case.	Can not be given.	Wagons of simil types but ma of other ma rials are n purchased at t same time.
		36·800	...				
		...	16·600				
		17 000	..				
		...	...				
		8·000	...				

ron and steel.

Table B (*continued*).

21	22	23	24	25	26	27
Resistance these wagons to atmospheric influence heat, cold, rain, damp.	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards. Life.	Need of repair	Cost of repair.	Resistance to violent damage.	Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
unfavourable sults have been tained.	The types named will probably be made of the same material in future.	Up to the present no unfavourable observations have been made.				Iron wagons can be recommended for the carriage of manure, coal, slag and ballast.
inside walls the body have equently to be ated to protect them against ist.	Open goods wagons and crocodiles, having a tonnage of 20 tons or more, will also be made in the future wholly of iron.	Have given good results as a rule.				Iron wagons are chiefly in the form of open wagons for bulk goods, of crocodiles and of special wagons for very heavy and large articles.
...	...	...	...	...	...	...
pinion can yet given.	Probably of other materials.	According to the observations hitherto made, these wagons do not seem to give satisfactory results, as it is probable that repairs will cost more, and as there are difficulties in the way of keeping spare pressed parts.				According to present experience the exclusive use of iron for making goods wagons does not seem advisable.
d.	Wagons of the same type, of same materials. It is not proposed to make other wagons of iron or steel.	The wagons have given goods results. There has been no violent damage.				Yes, for self-discharging wagons.
...	Of the same materials	Reduction of tare; greater durability.				Suitable for the traffic (goods) named.

Table B *(continued)*. **Goods wagons made wh**

1	2		4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wagons in use since
	AUSTRIA *(continued)*.				
9	Bukovinia Local Railway.				
10	Aussig-Teplitz Railway				
11	Austrian North Western Railway. .	←			
12	Austrian Southern Railway				
13	Vienna-Aspang Railway				
	HUNGARY.				
14	Mohacs-Pecs Railway				
15	Arad-Csanad Railway	←			
16	Hungarian State Railway.	255	Two-axled coal wagons of older type. . . .	...	1868
		1,453	Two-axled coal wagons of newer type . . .	15	1891
		84	Two-axled manure wagons	16	1885
		453	Two-axled low-sided wagons of older type . .	...	1877
		500	Two-axled low-sided wagon of newer type . .	...	1909
		153	Four-axled low-sided wagons	...	1882
		61	Three-axled platform wagons	...	1866
		31	Six-axled coal wagons of Talbot type	18	1908
		35	Two-axled gas trucks	19	1892
		247	Two-axled tank trucks.	...	1869
		1,064	Tank trucks, privately-owned	...	...
	BELGIAN.				
17	Belgian State Railway.	41	Four-axled platform wagons for carrying rails.	20	...

iron and steel.

Table B *(continued)*.

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Dimensions of body, inside. Width, in millimetres.	Dimensions of body, inside. Height, in millimetres.	Dimensions of body, inside. Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
ne.							
ne.							
n order to have a smaller tare for the same tonnage.	Rolled sections and rolled plate. The brakesman's cabins of the wagons have wooden walls. The floor of the low-sided wagons is made of deals.	4,434	2,604	1,263	...	2·53	11·3
		6,594	2,600	1,150	18·2	3·60	15
		6,300	2,600	1,150			
		7,000	2,650	940	17·4	3·80	12·5
		7,200	2,500	470	...	3·66	11·3
		9,200	2,600	470	...	6·00	15·0
		10,100	2,400	500	...	6·5	20·0
		12,000	2,800	...	...	7·00	20·0
		11,600	2,850	...	43·5	11·900	40·0
		7,000	1,250 diameter.	...	24,000 litres.	4·000	10·0
		...	...	...	...	...	10·0
		...	...	...	...	...	10·15
	...	1,850	2,830	...	...	13·6	35·0

Table B *(continued)*. **Goods wagons made wh**

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost pr of these wagon to cost price of wago of similar type ma of other materia
	AUSTRIA *(continued)*.						
9	Bukovinia Local Railway. . . .						
10	Aussig-Teplitz Railway						
11	Austrian North Western Railway. .	←					N
12	Austrian Southern Railway						
13	Vienna-Aspang Railway						
	HUNGARY.						
14	Mohacs-Pecs Railway						
15	Arad-Csanad Railway	←					N
16	Hungarian State Railway.	6·4	5·5	Steel / Iron and wood = Tons. 5·5 / 5·4 = 1 / 0·982		...	Wagons of the me type made other materi were not orde at the same riod.
		6·9	5·9	Steel / Iron and wood = Tons. 6·9 to 7·1 / 6·7 to 6·8 = 1 / 0·985 to 0·945		4,060-4,580 with brake 3,540-3,750 without brake.	
				Steel / Iron and wood = 5·9 to 6·0 / 5·7 to 5·8 = 1 / 0·984 to 0·95			
		7·25	6·6		For coal, ore, manure, sand and liquids.	4,640 with brake. 3,810 without brake.	
		6·3	6·15			...	
		7·9	6·74			5,400 with brake. 4,355 without brake.	
		13·50	...	There are no wagons of similar type made of wood and iron		...	
		...	10·6			6,40	
		24·6	22·4			20,870 with brake. 18,505 without brake	
		...	15·5			11,000-12,600	
		...	...			5,520 with brake. 4,500 without brake.	
		...	...			...	
	BELGIAN.						
17	Belgian State Railway.	...	...	...	...	...	...

on and steel.

Table B (*continued*).

21	22	23	24	25	26	27
Resistance hese wagons to tmospheric luence heat, cold, ain, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards. Life.	Need of repair	Cost of repair.	Resistance to violent damage.	Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
ne whole, wa- s with sides floor made of plate have given good lts as regards stance to wet, they readily ; coating of paint conse- ntly requires uent renewal. plates are liable to se- s injury.	Wagons for ma- nure, liquids and gas, as well as Talbot wagons, of the same mate- rials; in the case of other wagons, the underframe and the frame of the body of steel (iron), the walls and floor of wood.	1° The wagons have as a rule given good results for certain classes of traffic, such as manure and liquids, 2° The 6-axled Talbot coal wagons have only been in use for a short time, so that no results are yet available 3° Coal wagons made wholly of iron have not given good results in so far, more especially, as the floor made of iron plate has proved unsuitable, as it be- comes undulating, depressions form, and it consequently soon rusts through. The lower parts of the side and end plates are also exposed to rusting, and this makes expensive repairs necessary.				
...	...	...	..	..	...	...

Table B (*continued*). **Goods wagons made**

1	2	3	4	5	6
Item No.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wag... in use a...
	BULGARIA.				
18	Bulgarian State Railway				
	DENMARK.				
19	Danish State Railway				
	SPAIN.				
20	Andalusian Railway				
21	Great Southern of Spain Railway . .	100	Four-axled ore wagons, with hopper bottom.	21	19
		24	Two-axled ore wagons, with hopper bottom. .	22	19
22	Spanish Northern Railway				
	FRANCE.				
23	French Eastern Railway	...	Open goods wagons of older type	...	
		1	Two-axled open goods wagons	...	19
24	French State Railway	...	Four-axled coal wagons, Fox-Arbel type . .	...	Being at pr...
25	Midi Railway.	50	— high-sided wagons, Fox-Arbel type.	23	19
		100	— platform wagons, Fox-Arbel type.	24	19
26	Orleans Railway.	200	Two-axled coal wagons	17	19

on and steel.

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Width, in millimetres.	Height, in millimetres.	Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
e carriage of bulk goods .	...	6,255	2,286	1,830	...	9·144	35·0
... .	...	5,490	2,745	920	...	3·200	15 0
...	...	...	...	...	...	...	...
experiment.	Walls of pressed plate, floor of wood.	7,490	2,610	1,200	...	3·750	...
ler to obtain coal wagons ng a large tonnage, and a not exceeding 16 tons.	...	11,810	2,800	1,520	50	8·25	40·0
...	High-sided walls of pressed plate, floor of oak.	10,690	2,686	1,800	51·7	7·200	40·0 coal. 50·0 ore.
...		14,000	2,272	200	...	9·000	40
...	...	4,810	2,600	920	...	2·900	10

Table B (*continued*). Goods wagons made w

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost of these wa to cost price of wa of similar type of other mate
	BULGARIA.						
18	Bulgarian State Railway	←					
	DENMARK.						
19	Danish State Railway	←					
	SPAIN.						
20	Andalusian Railway	←					
21	Great Southern of Spain Railway . .	14·60	14·16	No comparison possible.	Especially for ore.	9,625	...
		7·43	7·265	Compared with 16-ton wagons of wood and iron, but without Hardy brake, 1 : 2·06 and 1 : 2·35.		6,800	Ratio to w wagons, 0
22	Spanish Northern Railway	←					
	FRANCE.						
23	French Eastern Railway	...	...	...	For the carriage of coal and ore.	...	...
		...	...	...		...	...
24	French State Railway	15·0 lever brake. 15·6 Brakesman's cabin.		...	For the carriage of coal; self-discharging.	...	...
		15·93 lever brake. 16·900 Brakesman's cabin.		Similar types of other material do not exist.	For coal and ore.	Brakesman's cabin. 10,600 Without Brakesman's cabin. 9,800	...
25	Midi Railway.	16·0 lever brake. 17·13 Brakesman's cabin.			For long timber and rails.	Brakesman's cabin. 14,200 Without Brakesman's cabin. 13,200	...
26	Orleans Railway.	5·90	5·12	A little less than similar wagons made of wood.	For coal.	2,785	Wagons same type of wood 2,890 fra the same

on and steel.

Table B (*continued*).

21	22	23	24	25	26	27
esistance ese wagons to nospheric ance (heat, cold, n, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards. Life.	Need of repair.	Cost of repair.	Resistance to violent damage.	Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
e paint is perly maiu- d, these wa- suffer less wooden wa-	Of the same material, when a demand arises.	Excellent, no wear and tear.	Very rarely.	High.	With violent treatment deformations are produced, but no fractures; can easily be repaired.	Specially suitable for large-capacity wagons. Less suitable for smaller wagons.
...	It is probable that steel will be used still more extensively, if the price becomes reduced and if wood goes up in price.	...	...	...	..	Seems to be suitable for wagons of great tonnage, which can be self-discharging.
...	...	Can only be determined after a longer period of time.				
...	...	...	...	..	..	...
pinion can yet be given as they have been in use too short a time.						..
...	Underframe of iron, frame of body of iron, walls of wood.	..	..	..	...	.

Table B *(continued)*. **Goods wagons made w**

1	2		4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wago in use sin
	FRANCE *(continued)*.				
27	French Northern Railway	80	Four-axled high-sided wagons	25	190
		170	Four-axled platform wagons.	26	190
28	Paris-Lyons-Mediterranean Railway .	99	Four-axled coal wagons	30	190 190
		3	Four-axled platform wagons for small locomotives.	27	190
		4	Four-axled platform wagons.	31	190 190
		1	Four-axled special wagons for large plate . .	32	190
		...	Coal wagons	..	...
29	Tarn Department Railway	←			
30	Algerian lines, State Railway . . .	←	None. Should the traffic make it necessary to obtain goods		
	GREAT BRITAIN AND IRELAND				
31	Caledonian Railway	400	Four-axled high-sided wagons	...	190
		12	Four-axled hopper mineral wagons	...	190
		35	Two-axled gunpowder vans	...	190
32	Great Central Railway.	About 230	Two-axled coal wagons.	33	190
			Two-axled coal wagons, self-discharging. . .	...	190
			Four-axled coal wagons	...	190
			Four-axled coal wagons	34	190

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Dimensions of body, inside. Width, in millimetres.	Dimensions of body, inside. Height, in millimetres.	Dimensions of body, inside. Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
der to reduce the tare. . .	The high-sided walls are made of pressed steel plate. Ultimate tensile strenght, 45 to 50 kilograms per square millimetre.	11,824	2,800	1,520	...	8·250	40
	Underframe parts; ultimate tensile strength, 50 to 55 kilograms per square millimetre. Floor made of steel.	15,000	2,810	...	...	10·40	40
n experiment; obtained from erica.	Made of pressed plate	11,455	2,610	1,200	...	8·255	30
...	...	8,500 9,150	1,370	...	...	5·5 5·7	40
nsequence of the great tonge, 40 tons.	...	14,550	2,600	...	...	11·20	40
	...	20,000	...	...	...	14·00	40
...	Wholly of iron, but floor of wood.	...	...	...	...	...	...
capacity, it is intended to build them wholly of steel.							
der to obtain a lighter tare and eater durability and safety.	...	10,675	2,440	1,320	...	7·32	30·48
		10,675	2,440	...	...	8·08	40·64
...	...	4,730	2,440	...	...	...	...
der to reduce train length and e weight.	...	6,350	2,350	1,473	...	3·658	20·32
		5,480	2,300	2,230	...	3·050	15·24
...	...	11,580	2,307	1,270	...	8·230	30·48
...	...	11,580	2,490	1,525	...	8·230	40·64

*

Table B (*continued*). **Goods wagons made wh**

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost p of these wago to cost price of wag of similar type m of other materi
	FRANCE (*continued*).						
27	French Northern Railway	15·15·5	...	There are no wagons of the same type but of other material.	Can only be used for goods in bulk, coal, ore, and as platform wagons.	14,285 et 14,885	No compari possible.
		14	...			9,290	
28	Paris-Lyons-Mediterranean Railway .	15·840	...	There are no wagons of the same type but made of other material.	These wagons seem to be specially suitable for the conveyance of coal, ore and heavy goods.	8,600	No compari possible.
		10·210	...			8,350	
		19·74	...			9,850	
		19·55				14,150	
		20·90	...			13,600	
		...	...			17,050	
						...	
29	Tarn Department Railway	←					
30	Algerian lines, State Railway . . .	←			None. Should the traffic make it necessary to obtain goods w		
	GREAT BRITAIN AND IRELAND.						
31	Caledonian Railway	13·000	...	No comparison can be made between these new wagons and the old ones.	General merchandise not requiring a covered wagon.	6,084	No compari possible.
		17·475	...			7,488	
		8·640	...			3,848	
32	Great Central Railway.	8·990	8·636	Tare of timber-built 10-ton wagons, 6 tons; tare of 20-ton wagons of steel, 20 tons.	The wagons are used solely for coal.	...	...
		...	...				
		14·376	...				
		15·138	...				

n and steel.

Table B *(continued).*

21	22	23	24	25	26	27
istance e wagons to spheric nce (heat, old, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards. Life.	Need of repair	Cost of repair.	Resistance to violent damage.	Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
uitable, in se of heat, wagons of wood. ron bottom probably out quicker if made of . The same ies to the if the plate thin.	No other types are at present under consideration. When more 40-ton wagons are ordered, the sides and floors will be lined with wood.	Sufficient experience is not yet available owing to the short time they have been in use.				Only suitable for large tonnage such as 40 tons. It is feared that the wall and bottom plates will be strongly attacked by rust.
the present e wagons resisted at-heric action	Wagons of the same type will in the future be built in the same way. Steel is used generally for the underframe and the running gear. The floor and the body of covered wagons will however be made of wood, as lighter and less affected by changes of temperature.	The wagons have only been in use a short time, hence no experience is as yet available,				The exclusive use of steel is to be recommended in the case of wagons used for the conveyance of coal, ore and large and heavy goods.
capacity, it is intended to build them wholly of steel.						
ng enough e to show; ey seem to e repaint-	No intention of extending the use of steel or of using any other material.	Wagons of steel are safer in working, more durable, lighter in tare, have greater capacity and are safer from fire. Repairs are not much required, except in cases of accidental damage. The wagons do not stand violent treatment so well as timber wagons.				Generally no; only for large capacity wagons.
ell painted, agons dete-e rather ; and it is ly possible ep paint on nside of a vagon, par-ary on the n. The latter cordingly of timber in of the wa-	Undecided.	Satisfactory.	Require less lighter repair than timber wagons.	When badly smashed, more expensive than with timber wagons.	Superior to timber wagons.	No, unless extra care is given to painting and maintenance timber pratically wants no protection and still gives a reasonable life.

Table B (*continued*). Goods wagons made w

1	2	3	4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wag in use si
	GREAT BRITAIN AND IRELAND (*continued*).				
33	Great Eastern Railway	←		Only special wagons	
			Two-axled ballast wagon	36	
			Two-axled ballast wagon	37	
			Two-axled ballast wagon, with hopper	38	
			Two-axled coal wagon, with hopper	...	187
34	Great Western Railway	About 4,000	Two-axled coal wagon	...	
			Two-axled coal wagon	39	
			Two-axled coal wagon, with hopper	...	
			Four-axled coal wagon	40	
35	Lancashire & Yorkshire Railway	12	Two-axled covered gunpowder vans	...	1905
		110	Two-axled coal wagons, hopper	...	1904
		2	Four-axled well wagons	...	1904
		2	Four-axled well wagons	...	1903
		24	Four-axled tramcar trolleys	...	1899
		6	Four-axled boiler wagons	...	1893
		6	Two-axled well wagons	..	1898
36	Midland Railway	200	Two-axled coal wagons	...	1882
		70	Four-axled coal wagons	35	1899
		102	Special wagons for rails, boilers, armour plates, etc.	...	...
			Four-axled hopper coal wagen	41	1903
			Four-axled high-sided wagon	42	1903
37	North Eastern Railway	475	Four-axled bolster wagons	43	1905
			Two-axled ironstone wagon	...	1905
			Special wagons for boilers, etc.	...	...
38	South Eastern & Chatham Railway	←			

ron and steel.

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Width, in millimetres.	Height, in millimetres.	Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
yance of locomotive coal.							
	...	4,870	2,285	534	...	2·745	8·23
	..	6,395	2,590	725	...	3·660	20·32
	...	4,575	2,278	2,005	...	2·894	20·32
e durable	...	4,575	2,288	1,968	...	2·894	12·19
	...	4,880	2,440	953	...	2·745	10·16
	...	6,405	2,355	1,475	...	3·660	20·32
	...	6,405	2,364	2,364	...	3·965	20·32
	...	13,105	2,355	1,475	...	9·450	40·64
ying explosives	...	4,880	2,300	1,950	....	...	10·16
educe tare and increase car-ng capacity.	..	6,465	2,440	...	...	...	20·32
not possible to carry such ds with wagons built of tim-r.	..	12,505	2,440	....	...	9·45	25·4
	...	13,878	2,440	...	...	11·10	52·8
cial shape of the wagons . .	...	12,149	2,520	...	...	9·45	15·24
	...	10,980	2,365	...	...	7·168	36·58
	..	732	2,490	...	...	...	6·1
btain maximum strength with nimum tare.	...	6,550	2,410	1,470	...	3·660	20·32
	Made of Fox pressed plate . .	10,970	2,265	1,320	...	7·315	30·48
	...	...	...	...	...	...	...
btain a strong and rigid struc-re and a low tare.	...	10,675 10,675 10,965	2,275 2,275 2,275	. . ..	... .	8·49 8·49 8·25	32·512 40·640 40·640
	...	10,980	2,275	1,525	...	7·93	30·480
	..	11,005 14,030	2,440 2,440	... ...	... ...	7·625 10·37	32·51 40·64
	...	6,085	2,300	...	...	3·200	30·48
	...	...	...	...	...	...	...

Table B (*continued*). Goods wagons made v

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost of these wag to cost price of wa of similar type of other mate
	GREAT BRITAIN AND IRELAND (*continued*).						
33	Great Eastern Railway	←					Only special wagons
34	Great Western Railway	5·35	...	...	For coal and for ballast.	...	...
		...	8·49				
		7·825					
		6·15					
		5·895					
		8·740					
		9·30					
		18·95					
35	Lancashire & Yorkshire Railway . .	...	7·935	Can not be given, as there are no wagons of the type built of other material.	...	2,990	No such co rison is poss
		8·84	...		...	3,120	
		...	16·97		..	5,150	
		...	32·56		...	13,000	
		...	17·985		...	6,500	
		...	16·72		...	6,470	
		...	8·485		...	3,640	
36	Midland Railway	8·585	...	...	For coal and for special articles.	...	Cannot be st as no simila hicles are b
		13·515	...	...		...	
		...	...	...		...	
37	North Eastern Railway	13·82	...	The tare of an open 40-ton wagon 38 feet long is 18 tons when of composite structure. The tare of a similar all-steel wagon is 15 tons.	Not suitable for salt or other bulk freight that forms a corrosive solution with water. Also not suitable for covered wagons when the freight requires protection from changes of temperature.	The cost price varies from £ 17 to £ 20 per ton of finished weight, and the equivalent per ton of capacity is from £ 8 to £ 9, according to design and to fittings.	The cost of nary wagon low capacity of timber struction v between £ 1 £ 18 per t finished wa and between £ 15 pe of capacity.
		16·51	...				
		16·41	...				
		13·36	...				
		13·32	...				
		18·90	...				
		12·09	...				
		...	...	...			
38	South Eastern & Chatham Railway .	←					

ron and steel.

Table B (*continued*).

21	22	23	24	25	26	27
tesistance hese wagons to mospheric uence (heat, cold, in, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards.				Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
		Life.	Need of repair	Cost of repair.	Resistance to violent damage.	
vance of locomotive coal.						
enough experience.	...	No experience.				For the types mentioned, as it is more durable and convenient.
sufficient experience.	The same materials, as far as the same types are concerned.	...	.	..	...	Not for all types, but only for those mentioned.
n susceptible deterioration rust.	No intention to depart from present practice.	The advantages of goods wagons built of steel (iron) consist in greater strength and lighter tare.				For special types only.
ate not favourle to the dulity of steel ctures; a larproportion of mileage is cted by the sea breezes; aping and ating must efore be atled to.	It is not intended to adopt all-steel construction for short four-wheeled wagons. Timber is not used for large wagons, except for the bodies of the covered wagons for perishables.	After five years of service the vehicles are straight and true to form; the corrosion is not serious; the paint must be renewed at average intervals of two and a half years.	Headstocks have suffered by rough shunting; steel buffer sockets to transmit the shock to the longitudinal members have obviated the recurrence of this trouble.	Many of the wagons have been used for experiments with automatic couplers, continuous brakes, etc., so that the expenditure on ordinary maintenance cannot be given.	In some cases of derailment no serious damage resulted.	Broadly speaking all-steel construction is recommended for wagons of 25-ton capacity and upwards, except in the case of wagons for perishables.

Table B (*continued*). Goods wagons made wh

1	2	3	4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wagon in use sinc
	GREAT BRITAIN AND IRELAND (*continued*).				
39	Great Southern & Western Railway .	42	Two-axled hopper-bottom ballast wagons . .	...	1903
		42	Two-axled hopper-bottom coal wagons . . .	...	1884
40	Hull and Barnsley Railway				
41	Isle of Man Railway				N
42	London-Tilbury & Southend Railway .	25	Two-axled gunpowder vans	...	1903
		2	Four-axled well wagons	...	1903
43	Taff-Vale Railway	53	Two-axled covered goods wagons	...	1904
	EMPIRE OF INDIA.				
			Two-axled covered goods wagons	44	Not avail
			Two-axled low-sided goods wagons	...	
44	Eastern Bengal State Railway. . .	About 9,000	Two-axled coal wagons	45	
			Four-axled timber and boiler trucks	...	
			Four-axled covered goods wagons, narrow-gauge.	46	
			Two-axled coal wagons	...	
			Two-axled goods wagons.	47	About 1
45	East Indian Railway	21,000	Two-axled coal wagons	48	
			Four-axled high-sided wagons	49	
46	Great Indian Peninsula Railway .	About 90 per cent of the stock. 4,815	Two-axled covered goods wagons	50	About 1
				51	
		3,248	Two-axled high-sided wagons	52	
		494	Timber wagons	...	
		82	Miscellaneous wagons.	...	

iron and steel.

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside.				Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
		Length, in millimetres.	Width, in millimetres.	Height, in millimetres.	Cubical capacity in in cubic metres.		
e difficulty of building a wooden vagon with hopper door.	...	4,575	2,480	...	...	2·900	20·32 12·2
	...	...	...	...	...	...	10·16
ety from fire, and traffic requi-ements.	The vans have a wood lining inside.	4,785	2,170	2,390	...	2·745	7·112
	...	15,655	2,390	...	...	12·300	20.32
an experiment.	...	5,285	2,167	...	...	...	10.16
periority to any other material.	....	8,410	2,895	2,540	...	4·880	18·54
		5,798	2,745	2,420	...	...	16·25
	..	5,890	2,890	1,065	...	3·505	20·32
		5,870	2,590	716	...	...	11·63
	..	5,870	2,845	1,525	...	3·505	17·77
	..	16,165	2,745	...	...	13·265	28·00
	...	13,115	2,265	2,390	...	8·840	18·41
	..	5,495	2,495	1,016	...	...	8·34
el was considered an improve-ient on wood.	The bottom of the coal wagon has a covering of teak.	7,015	2,840	2,454	...	3·965	23·52
		5,870	2,840	1,525	...	3·510	23·52
	..	12,810	2,900	1,980	...	9·145	43·43
re adaptable to climatic condi-ons, and the limitations impo-ed on us by timber.	...	5,635	2,595	...	...	3·200	16·26
		5,865	2,745	...	...	3·500	20·32
	..	5,890	2,745	1,145	...	3·500	16·26
		7,340	2,745	915	...	4·575	20·32
	..	...	...	...	..	...	...
	...	...	...	...	...	...	...

Table B (*continued*). **Goods wagons made w**

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost of these wag to cost price of wa of similar type of other mate
	GREAT BRITAIN AND IRELAND (*continued*).						
39	Great Southern & Western Railway .	7·84-8·25 5·1	...	Not possible, as there are no wagons of this class built of wood.	...	...	Comparis possible.
		7·1	...		...	...	
40	Hull and Barnsley Railway	←					
41	Isle of Man Railway						
42	London-Tilbury & Southend Railway .	8·280 19 300	... ...	No comparison possible.	For the conveyance of explosives.	...	There is no s stock of oth terial.
43	Taff Vale Railway	6·56	...	The same wagons of wood weigh 6.16 tons. Ratio, 1 : 1·067.	No experience.	...	...
	EMPIRE OF INDIA.						
44	Eastern Bengal State Railway. . .	9·90 8·13 8·18 6·66 8·89 20·78 10·00 5·85	... ...	... ...	Jute, coal, and large loads.	9,676 6,321 4,737 3,909 8,551 21,588	Not availabl
45	East Indian Railway	8·99 9·15 21·59	... ...	Not comparable as the dimensions differ.	The goods are used for all goods.	5,850 5,512 10,920 (Not including work in India.)	Can not be tained.
46	Great Indian Peninsula Railway . .	8·13 9·15	... ...	Unable to say.	Specially suitable for inflammable goods and explosives. Quite as suitable for other kinds of goods as wood vehicles.	7,630	Unable to sa
		8·13 9·15	... ...			8,304	
		... ...	... ...			7,166 ...	

iron and steel.

Table B (*continued*).

21	22	23	24	25	26	27
Resistance of these wagons to atmospheric influence (heat, cold, rain, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards. Life.	Need of repair	Cost of repair.	Resistance to violent damage.	Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
wing to the design of the wagon, the influence of rain is unimportant.	The same type will be built of steel.	Good.	Very little.	...	Greater than in the case of wagons of wood.	Only suitable for wagons with hopper bottom.
		Repairs generally mean a special equipment.				
...	The same stock of the same material.	Satisfactory in every respect; no trouble with derailments or collisions.				Greater safety for explosives and inflammable goods.
o experience.	Underframes of steel for carriages, and long underframes of steel for goods stock; but for short wood is found more convenient.	None that we know of.				...
tisfactory, provided well looked after as regards painting.	No intention to make the wagons of anything but steel.	Satisfactory results.				For all types of good stock.
he wagons are much better than those of wood.	It is intended to have the wagons built entirely of steel.	Satisfactory.				For all except the bodies of coaches; and we may come to them yet.
tisfactory. Do not retain heat onger then wood wagons and not specially subject o rusting.	Wagons will be built of steel in the future.	Satisfactory.	Considerably less than with wagons of timber.	Lower than with wagons of timber.	Much more able to resist bad treatment. Damaged only in bad cases.	For all types, except for the conveyance of live stock. In the latter case the floor must be made of wood to prevend slipping. For explosives the interior must be lined with wood, lead or india-rubber.

Table B *(continued)*. Cools wagons made wi

1	2		4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wagon in use sinc
	EMPIRE OF INDIA *(continued)*.				
47	North Western Railway (State Railway of India).	11,046	Two-axled covered goods wagons	56	About 1883
		612	Four-axled covered goods wagons	57 58	
		1,658	Two-axled low-sided wagons	59	
		242	Four-axled low-sided wagons	60	
		1,997	Two-axled high-sided wagons	61 62	
		16,174			
		70	Four-axled high-sided wagons	63	
		303	Two-axled flat wagons	...	
		12	Four-axled flat-wagons	..	
		101	Three-axled water trucks.	...	
		22	Two axled oil trucks	..	
		15	Gas trucks.	...	
			Two-axed covered goods wagons	64 65	1884
			Two-axled low-sided wagons	66	
48	Oudh and Rohilkhand Railway (State Railway of India).	5,000			
			Two-axled coal wagons	67	
			Two-axled flat wagons.	...	
	SOUTH AFRICA.				
49	Central South Africa Railways. . .	About 2,000	Four-axled high-sided wagons	55 54	Abou 1900
			Four-axled coal wagons, hopper	53	
50	Lagos Government Railways . . .	←			

ron and steel.

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Dimensions of body, inside. Width, in millimetres.	Dimensions of body, inside. Height, in millimetres.	Dimensions of body, inside. Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
eater strength and capacity with smaller tare.	...	5,945	2,745	2,395	...	3·050	20·57
		7,015	2,840	2,440	...	3·965	19·56
	...	9,760	2,745	2,440	...	6·100	23·37
		13,155	2,595	2,395	...	9·150	35·56
	...	6,550	2,885	760	..	3·580	22·78
		4,880	2,720	760	...	2·895	11·60
	...	9,760	2,745	610	...	6·100	24·385
	...	7,625	3,050	1,370	...	4·115	18·800
		5,870	2,845	1,480	...	3·505	19·300
	...	12,810	2,895	1,980	...	9·150	39·62
	...	6,710	2,590	...	...	4·270	13·36
	...	12,810	2,995	...	..	9·150	...
	...	8,080	2,590	1,145	...	2·44 + 2·44	22·915
	...	6,865	1,910 diameter	...	...	4·575	12·190
	...	5,595	1,270 diameter 3 units	...	...	4·880	...
...	..	5,490	2,590	2,465	...	3·505	11·17
		5,414	2,668	2,364	...	...	14·73
		5,490	2,745	2,446	...	3·505	16·25
		7,015	2,895	2,665	..	3·657	19·92
...	..	5,490	2,590	610	...	3·505	10·16
		5,871	2,745	740	...	...	10·16
		5,871	2,745	740	...	...	12·19
...	...	5,870	2,745	1,220	...	...	16·25
		5,870	2,846	1,525	...	...	17·99
		7,015	2,895	1,676	...	3·657	18·54
...	...	5,490	2,592	...	...	...	10·16
...	Longitudinals of Fox pressed plate.	11,300	2,365	965	...	7·32	27·18
		10,370	2,365	1,220	...	7·32	31·71
...	...	9,156	2,211	...	...	6·63	27·18
		11,130	2,287	...	...	7·83	36·24
		11,120	2,277	...	...	7·83	38·50

Table B (*continued*). Coals wagons made who

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost pri of these wagons to cost price of wagon of similar type ma of other material
	EMPIRE OF INDIA (*continued*).						
47	North Western Railway (State Railway of India).	8·380 8·890 15·240 21·335 7·670 6·010 12·955 9 550 9·145 21·135	7·875 .. .. 5·845 19·56 13·620 10·720 15·240	...	For all kinds of goods wagons.	...	...
48	Oudh and Rohilkhand Railway (State Railway of India).	7·15 7·15 8·13 8·64 5·69 6·60 6·60 7·82 9·15 9·91 4 82	...	...	...	Vary considerably and depend upon market price at time of ordering.	...
	SOUTH AFRICA.						
49	Central South Africa Railways . .	13·41 14·18 12·72 16·99 16·54	...	The ratio of tare to load is a greater one than in the case of partly-steel wagons.	For the carriage of all goods, especially for coal.	...	...
50	Lagos Government Railway . .	←					N

on and steel.

Table B (*continued*).

21	22	23	24	25	26	27
esistance ese wagons to nospheric uence (heat, cold, in, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards. Life.	Need of repair	Cost of repair.	Resistance to violent damage.	Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
factory in In-	The wagons will also be made of steel in the future.	Longer.	The wagons are stronger and more durable and the tare is smaller.	...	...	Yes, for all types.
ons built en- ely of steel on withstand climatic in- ences of In- better than od.	It is intended to build all goods stock of steel.	The wagons have greater strength and durability, and maintenance costs less.				For all types of wagons.
ible for the mate.	...	Wagons built entirely of steel have given every satisfaction so far. Nothing definite can yet be said about maintenance. Steel floors, sides and ends cost more in the first instance, but their life is much longer.				The exclusive use of steel cannot be recommended for all wagons; but they are suitable for rough minerals.

Table B (*continued*). **Goods wagons made wh**

1	2		4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wagons in use since
	SOUTH AFRICA (*continued*).				
51	Natal Government Railways. . . .		Four-axled low-sided wagons	68	Since 189 steel, pr ously of i
		2,103 of steel, 147 of iron.	Four-axled high-sided wagons	69 72 71	
			Four-axled well wagons	70	
	AUSTRALIA.				
52	New South Wales Government Railways	1,307	Two-axled open goods wagons.	75	1900
				76	1900
			Four-axled high-sided wagons	73	About 19
53	Tasmania Government Railways .	75	Four-axled low-sided wagons	74	
			Two-axled coal wagons	...	
	ITALY.				
54	Italian State Railway	100	Four-axled high-sided wagons	28	1907
			Four-axled platform wagons.	29	1907
		370	Two-axled high-sided wagons	...	1907
	LUXEMBURG.				
55	Luxemburg Prinz-Heinrich Railway	←			
	HOLLAND.				
56	Dutch State Railway	←			
57	Dutch Railway Company.	←			None

ron and steel.

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Dimensions of body, inside. Width, in millimetres.	Dimensions of body, inside. Height, in millimetres.	Dimensions of body, inside. Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
ngth and high capacity. . .	...	10,395	2,155	495	...	7·165	20
		10,995	2,210	495	...	7·320	22
		10,370	2,135	610	...	7·165	24
		11,005	2,230	685	...	7·320	35
	...	10,370	2,135	1,065	...	7·165	22
	...	11,005	2,210	943	...	7·320	24
	...	11,275	2,360	1,260	...	7·320	35
		11,005	2,210	1,450	...	7·320	35
	...	12,505	2,135	...	...	9·150	35
keep down tare and increase e carrying capacity.	...	5,480	2,660	912	...	...	15
		4,870	2,660	912	...	...	15
		4,870	2,653	885	...	. .	15
ability, light tare and low aintenance cost.	45 wagons all steel, 30 all steel except floors.	10,980	2,355	762	.	7·37	30
		10,980	2,355	380	...	7·37	30
		11,590	2,360	386	...	7·37	25
rder to test the durability and e advantages and disadvanta- es of this type.	Sides of pressed plate	14,000	2,686	1,200	...	9·0	40
	Floor of wood. { Longitudinals and trusses of pressed plate.	14,000	2,500	...	...	9·0	35
		14,000	2,550	...	...	9·0	40
	Sides of pressed plate	7,050	2,828	1,200	...	..	19
rucks.							

*

Table B (*continued*). **Goods wagons made wh**

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cost p of these wago to cost price of wag of similar type m of other mater
	SOUTH AFRICA (*continued*).						
51	Natal Government Railways. . . .	10·56	...	...	Suitable for all classes of goods.	...	...
		11·74	...				
		10·77	. .				
		14·33	...				
		11·33	...				
		11·83	...				
		14·43	...				
		16·56	...				
		15·09	...				
	AUSTRALIA.						
52	New South Wales Government Railways.	6·40	...	Ratio of tare of 15-ton steel wagon to tare of 8-ton wood wagon, 100: 83; of 15-ton steel wagon to that of 10-ton wagon with composite underframe, 100 : 94.	Only coal or coke in bulk.	15-ton wagons, about £175 each.	15 to 20 per higher; but comparis with wood gons made b steel was i duced.
		6·25	...				
		5·99	...				
53	Tasmania Government Railways . .	12·39	...	There are none of the same type built of wood.	Chiefly for coal.	Two-axled £200, four-axled £520.	There are no the same built of woo
		11·78	...				
		10·16	...				
	ITALY.						
54	Italian State Railway	16·70	...	With 20-ton wagons with two-axles the ratio is 940 : 924.	Used almost exclusively for the conveyance of coal.	£500 without duty.	Four-axled gons of the type are existence. axled wag wholly of and wooden gons of the period, 6 : 5.
		16·3	...				
		14·3	...				
		9·35	...			£240 on the average.	
	LUXEMBURG.						
55	Luxemburg Prinz-Heinrich Railway.	←					
	HOLLAND.						
56	Dutch State Railway	←					
57	Dutch Railway Company	←					None

on and steel.

Table B *(continued).*

21	22	23	24	25	26	27
Resistance these wagons to mospheric uence (heat, cold, in, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards.				Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
		Life.	Need of repair	Cost of repair.	Resistance to violent damage.	
...	...	...	...	...	...	...
limatic condi- s somewhat ct the dura- y in the case wagon bodies y.	The intention is to have the open goods wagons in future constructed entirely of mild steel.	Fairly satisfactory.	Slight.	Slight.	Fairly satisfactory.	Only for open goods wagons.
		On the whole the results may be considered favourable.				
factory.	10-ton wagons will be built of locally-grown wood, high-capacity wagons of steel with timber floors.	Generally satisfactory. The wagons have not been in use long enough to compare.				Only for high-capacity wagons.
under trial.	This depends on the results of the experiments.	The wagons are still under trial, as they only started running in 1907.				It appears probable that the exclusive use of steel is only suitable in the case of high-sided wagons.
rucks.						

Table B (*continued*). **Goods wagons made w**

1	2		4	5	6
Index number.	NAME OF RAILWAY.	Number of wagons.	Type of wagons.	Sketch of wagon. Number of figure.	Wago in use sin
	RUSSIA.				
	Russian State Railway. Catherine	1,773	Four-axled high-sided wagons	77	190
	Moscow-Kursk and Nijni-Novogorod.	100	Two-axled coal wagons	...	1906
58	Nicolas				
	Polesia				
	Syzran-Viazma				
	Tachkent				
59	Moscow-Windau-Rybinsk Railway.				
	SERVIA.				
60	Servian State Railway	350	Two-axled coal wagons	...	189
		3	Gas trucks.	...	188
		8	Tank trucks	...	189
		26	Two-axled coal trucks, narrow gauge.	...	...
	SWEDEN.				
61	Swedish State Railway	1,469	Three-axled ore wagons, self-discharging	78	188
62	Stockholm-Vesteras-Bergslagens Railway.				
	SWITZERLAND.				
63	Swiss Federal Railway	225	Two-axled coal wagons	79	189
64	St. Gothard Railway				
65	Rhetian Railway				
	TURKEY.				
66	Oriental Railway Company				

ron and steel.

Table B (*continued*).

7	8	9	10	11	12	13	14
Reason for having such wagons.	Particulars about design of wagon and materials used.	Dimensions of body, inside. Length, in millimetres.	Dimensions of body, inside. Width, in millimetres.	Dimensions of body, inside. Height, in millimetres.	Dimensions of body, inside. Cubical capacity in in cubic metres.	Spacing of axles or of bogie centres, in metres.	Tonnage, in tons.
ch greater capacity than could e obtained with wood wagons.	On the Arbel system, with walls of pressed plate.	13,450	2,870	1,470	58·0with.brakes 60·5with.brakes	9.4	37
	With turning ends	4,650	2,350	1,542	16·8	2·160	12·75
account of greater durability nd lower maintenance cost.	...	...	...	...	...	...	10 15
	...	...	...	...	...	...	10
	...	...	...	...	...	...	12
	...	...	...	...	...	...	...
ater strength	...	4,400	2,380	...	...	..	35
ater durability of the wagon ody.	...	5,770	2,790	1,300	...	3.500	15

Table B (*continued*) — Cools wagons made v

1	2	15	16	17	18	19	20
Index number.	NAME OF RAILWAY.	Tare. With brake, in tons.	Tare. Without brake, in tons.	Ratio of tare of these wagons to tare of wagons of similar type made of wood or of wood and iron.	For what classes of goods are those wagons most suitable?	Cost price of these wagons, in francs.	Ratio of cos of these wa to cos price of w of similar type of other mat
	RUSSIA.						
	Russian State Railway. Catherine	16·7	15·4	...	No special advantages.	With brake 12,600; Without brake 10,800,	...
	Moscow-Kursk and Nijni-Novgorod.	5·73	...	...		5,400	
58	Nicolas						
	Polesia	←					
	Syzran-Viazma						
	Tashkent						
59	Moscow-Windau-Rybinsk Railway.						
	SERBIE.						
60	Servian State Railway	6·00 8·00	...	There are no wagons of the same type of wood.	For coal.	2,370 to 4,130	...
		9·6 12·91	...		...	6,860 to 7,000	
		7·885	...		...	5,265	
		...	...		...	...	
	SWEDEN.						
61	Swedish State Railway	10·9	...	No comparison possible.	Ore.	6,430	Cannot be g
62	Stockholm-Vesteras-Bergslagens Railway.	←					
	SWITZERLAND.						
63	Swiss Federal Railway	8·20	...	There are no similar wagons of wood.	For the conveyance of coal.	3,300	...
64	St. Gothard Railway	←					
65	Rhetian Railway.						
	TURKEY.						
66	Oriental Railway Company.	←					

on and steel.

Table B (*continued*).

21	22	23	24	25	26	27
esistance ese wagons to nospheric uence (heat, cold, in, damp).	Of what materials are these wagons to be made in the future?	Avantages and disadvantages of wagons made wholly of steel and iron as regards.				Is the exclusive use of steel and iron for making wagons of the types in question, or of which types, advisable?
		Life.	Need of repair.	Cost of repair.	Resistance to violent damage.	
resists damp s.	It is not intended to continue to build these types. Of steel.	Damage often occurs owing to the weak construction of the bogies; these are accordingly strengthened. Repairs are expensive and take a long time. Special advantages have not been determined.				Only for special types, for instance self-discharging.
...	For coal, in future also of steel; there is no intention of building other wagons of steel.	The steel wagons are more durable, are more rarely damaged and resist better in case of derailment.				...
climatic influences are significant.	Ore wagons will also be made of steel in the future.	A proof of the durability is that the wagons have been in use since 1888. Cost of repair in 1906 ; 2·18 kroner par 1,000 axle-kilometres.				Experience is only available as far as ore wagons are concerned; for these steel is best.
factory.	Except in the case of coal wagons, the bodies of all types will be made of wood.	Longer life and less maintenance cost.				Specially for coal wagons.

Table C.

COUNTRY.	Total wagons.	Covered goods wagons.			Open goods wagons, high-sided and low-sided.								
		two axles.		four axles.	two axles.				four axles.				
		10	16 / 20	24 / 35	10	12.5	15	20	20 / 25	30	27 / 38	37	40
		Tonnage, in tons.											
Germany	10,236	...	...	...	749	...	...	9,365	...	...	...	...	...
Austria	3,812	...	...	...	...	...	...	...	...	...	...	...	...
Hungary	4,336	...	...	...	453	...	2,208	...	153	...	...	...	...
Belgium	41	...	...	...	...	...	...	...	...	...	...	...	...
Spain	124	...	...	...	...	...	...	...	...	...	...	...	...
France	708	...	...	...	201	...	...	...	...	99	...	...	180
Great Britain, India and colonies:													
Great Britain	5,850	53	...	...	†	†	†	200	...	470	...	...	12 †
India	59,513	...	15,943 (2)	612	†	...	6,903 †		242	† ...	...	...	70 †
South Africa	4,450	...	...	...	...	...	...	...	...	...	2,250	...	...
Australia	1,382	...	...	...	...	...	1,307	...	...	75	...	...	...
Italy	470	...	...	...	...	...	...	370	...	...	...	...	100
Russia	1,873	...	...	...	...	100	...	...	...	...	...	1,773	...
Servia	361	...	...	...	...	...	350 (4)	...	...	...	...	...	...
Sweden	1,469	...	...	...	...	..	...	...	...	...	...	...	...
Switzerland	225	...	...	...	...	...	225	...	...	...	...	...	...
All countries.	94,850	53	15,943 †	612	1,403 †	100 †	20,928 †		395	644 †	2,250	1,773	362 †

(1) 20-ton two-axles self-discharging, at present being built. Number not stated.
(2) One of these for the carriage of large plates.
(†) The different railways only gave the total number of the wagons, stating that they are of the types and tonnages mentioned, but v
giving the number of each type.

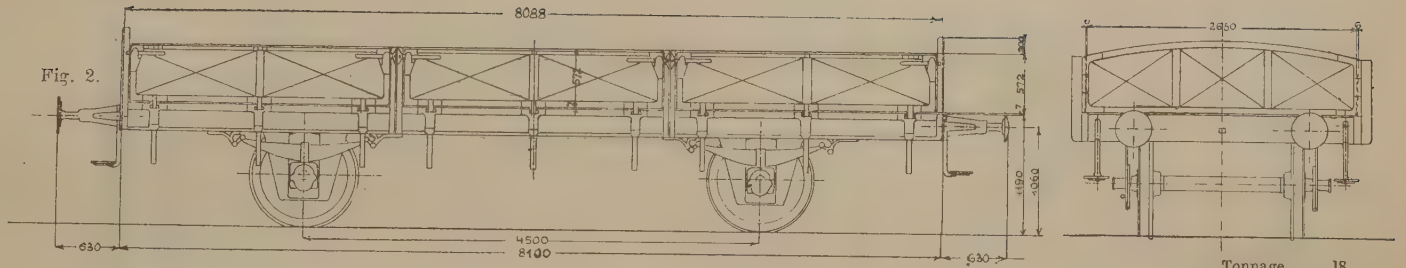
Table C.

ed.

Self-discharging coal wagons.						Platform wagons.								Wagons for special purposes.															
wo les.		four axles.			six axles.	two axles.	three axles.	four axles.					six axles.	manure, two axles, 12·5 tons	slag, two axles, 18 tons.	Gun-powder.		ore.					Gun, eight axles, 70 tons.	Tank, two and three axles, 10 to 24 tons.		Gas, two axles.				
																Two axles.		Two axles.			Three axles.	Four axles.							
17	2	27/38	38	40	40	6	20	15	20	25	35	40	50			7.1	10	15	20	30	35	35							
Tonnage, in tons.																													
10	...	...	51	...	...	...	...	...	...	...	...	4	...	8	8	6	...	...	...	...	...	...	...	...	...	...	...	...	...
...	(1)	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	157	...	...	...	1	3,608	46			
...	...	...	...	...	31	...	61	...	...	...	...	...	...	...	84	...	...	...	...	...	...	...	...	...	1,311	35			
...	...	...	...	...	...	...	...	...	...	...	41	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	24	...	...	...	100	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	178 (2)	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
...	194	...	...	...	...	...	...	24	2 (1)	2	6 (1)	1	2	...	...	...	25	47	...	...	1	...	...	...	...	...			
...	...	...	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...			
...	...	2,000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3	8			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1,469	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...			
10	194 1	2,000	51	...	31	1	61	24	2 1	2	49 1	182 1	2	8	92	6	25	47	24	157	1	1,469	100	1 (1)	4,922	89			

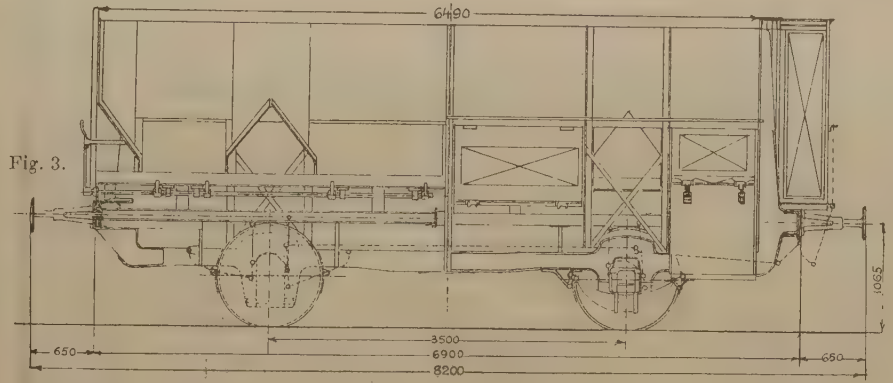
(2) Ditto. 90 to 100 per cent of the rolling stock of the railways consists of wagons made wholly of steel.
(4) Including also 10-ton wagons. In addition 26 coal wagons (two and four axles) for narrow-gauge lines.

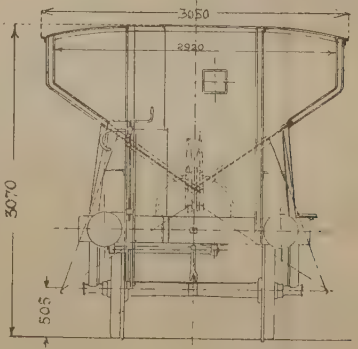
Fig. 2.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{18}{8{\cdot}98} = 2{\cdot}0.$$

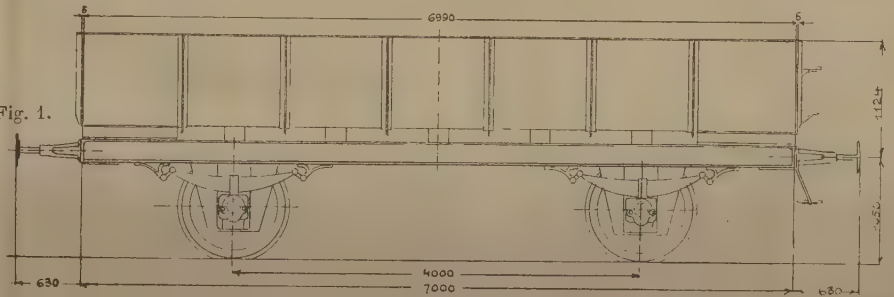
Fig. 3.

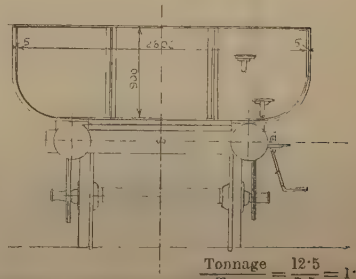




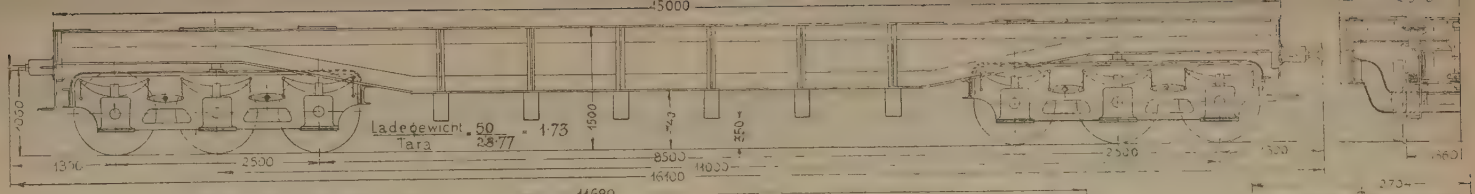
$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{17}{10} = 1{\cdot}7.$$

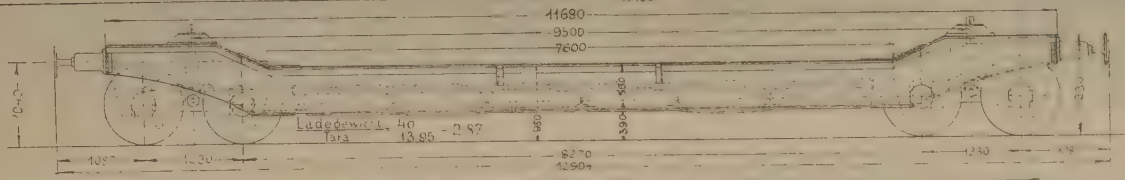
Fig. 1.





$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{12{\cdot}5}{7{\cdot}5} = 1{\cdot}66.$$





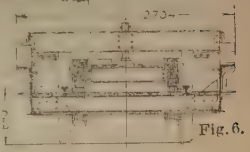
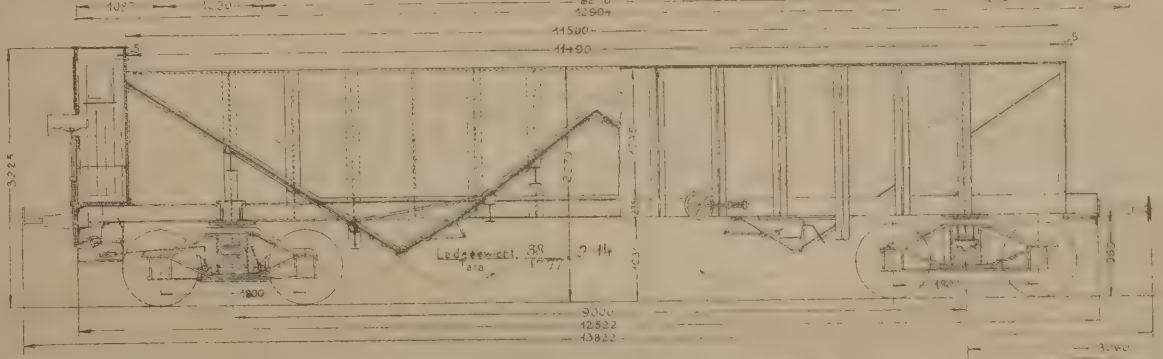


Fig. 6.



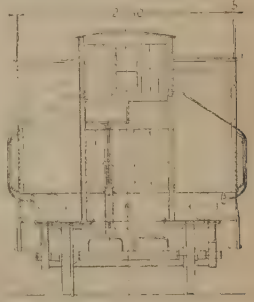
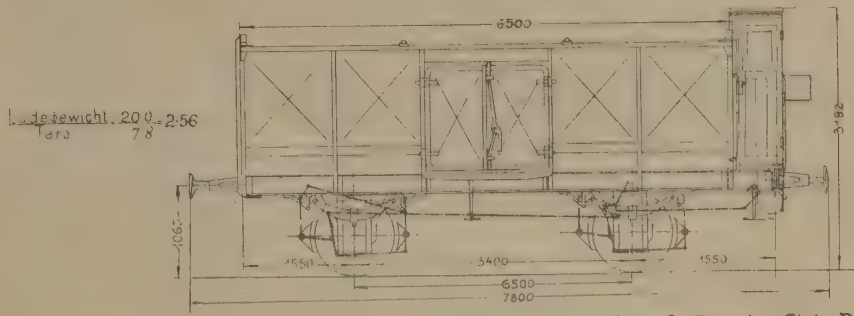


Fig. 5.



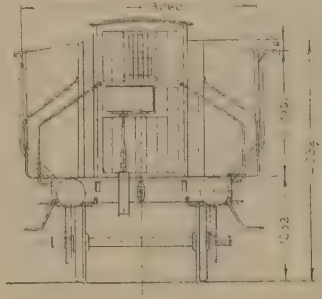
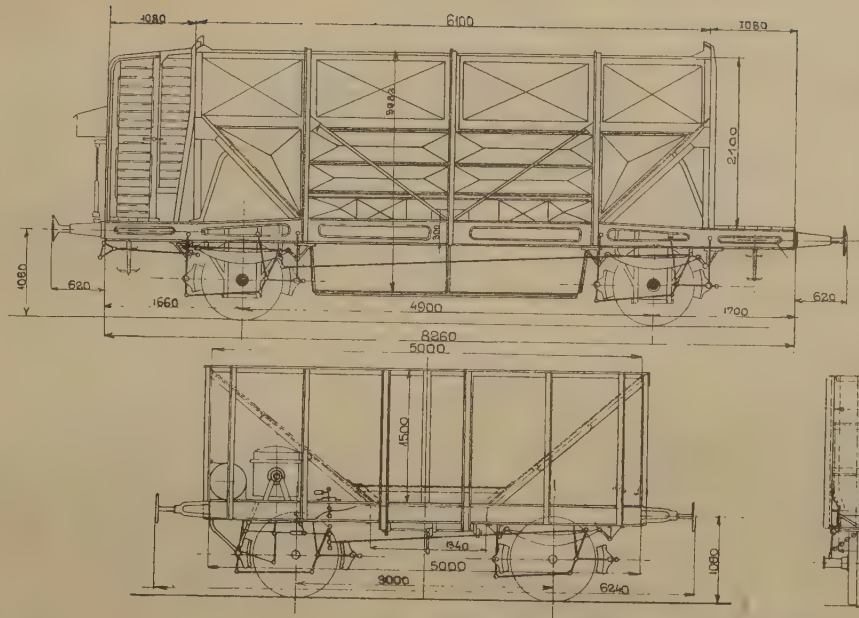


Fig. 4.

Figs. 4 to 7. — 3. Bavarian State Railway.

Explanation of German terms : Ladegewicht = Tonnage. — Tara = Tare.



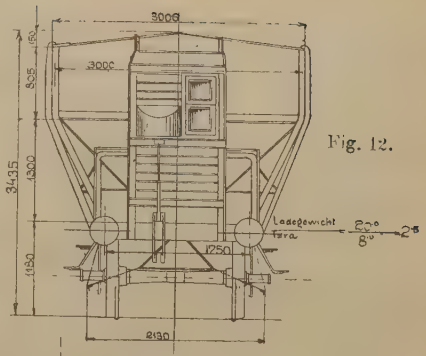


Fig. 12.

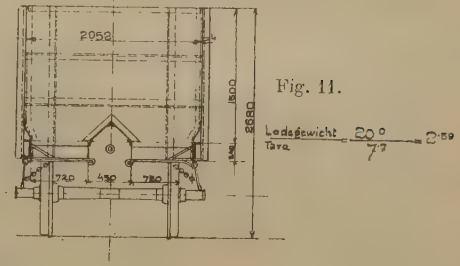


Fig. 11.

Figs. 11 and 12. — 8. Austrian State Railway.

Fig. 10.

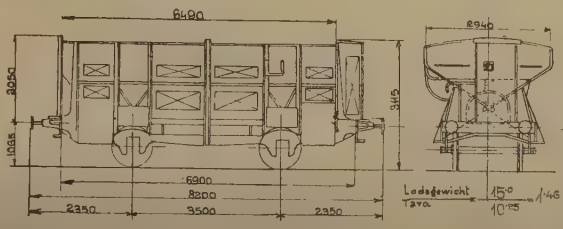


Fig. 10. — 6. Saxon State Railway.

Fig. 8.

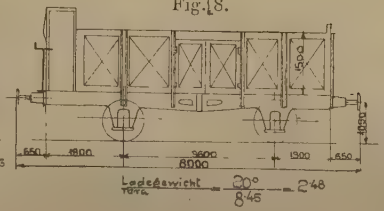
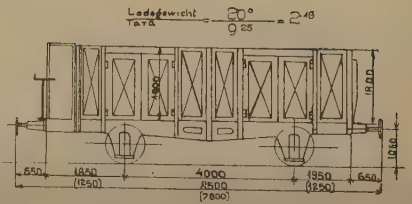


Fig. 9.



(The numbers in brackets apply to the wagons without brake.)

Figs. 8 and 9. — 5. Prussian State Railway.

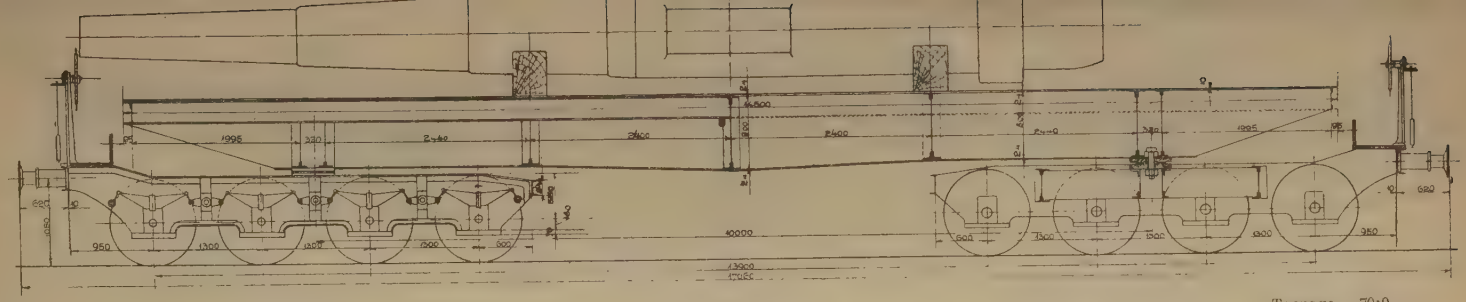


Fig. 13.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{70{\cdot}0}{36{\cdot}8} = 1{\cdot}9$$

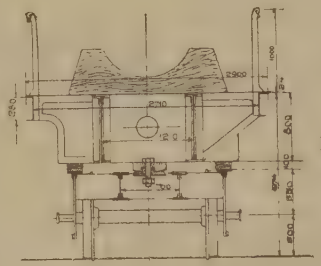
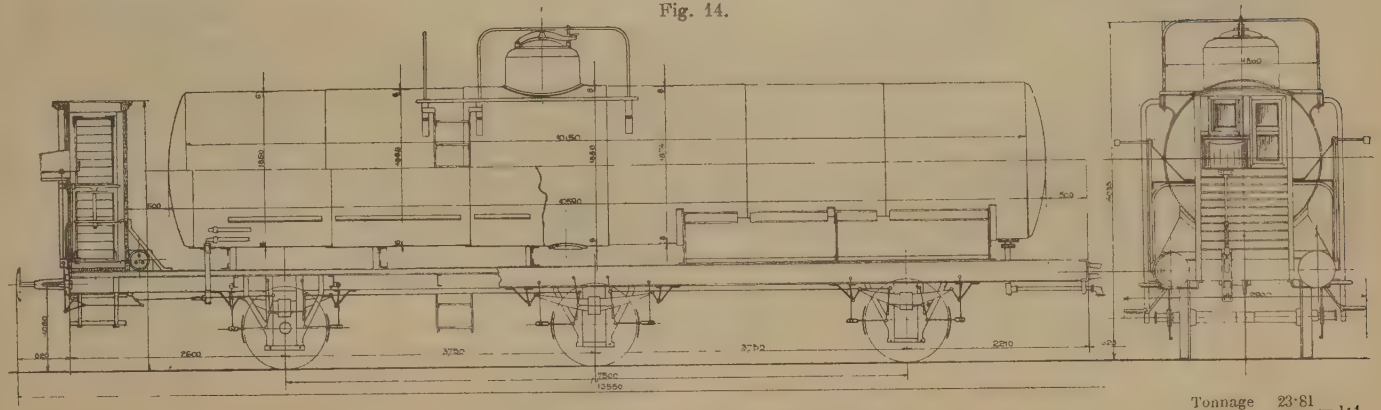


Fig. 13 (*continuation*).

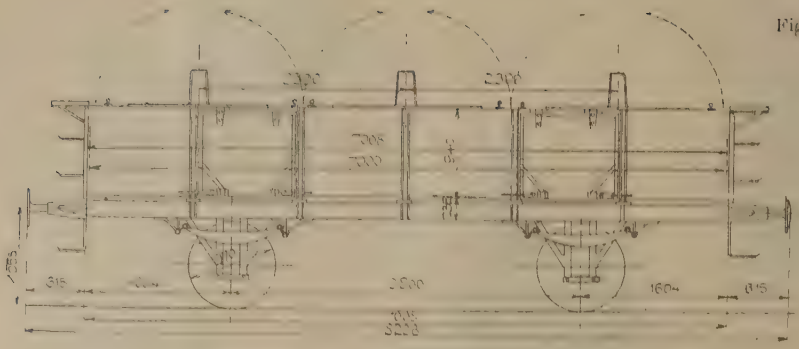
Fig. 14.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{23{\cdot}81}{17{\cdot}0} = 1{\cdot}4.$$

Figs. 13 and 14. — 8. Austrian State Railway.

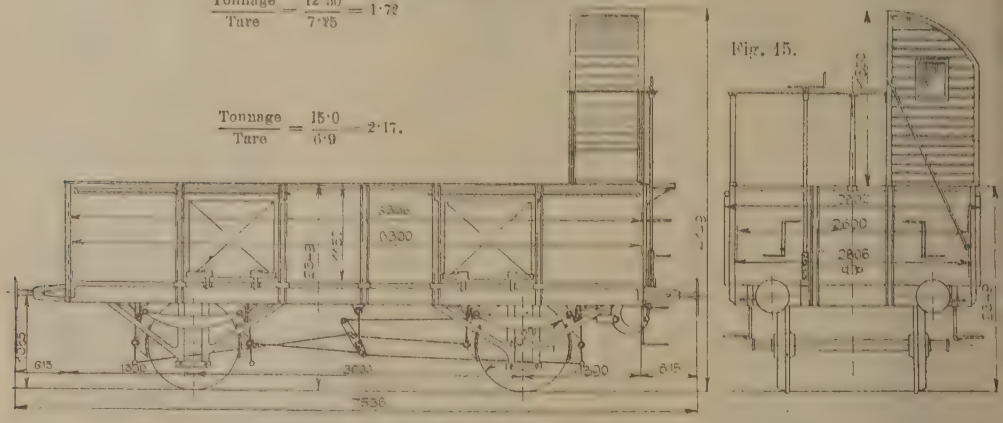
Fig. 16.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{12{\cdot}50}{7{\cdot}25} = 1{\cdot}72$$

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{15{\cdot}0}{6{\cdot}9} = 2{\cdot}17.$$

Fig. 15.



Figs. 15 and 16. — 16. Hungarian State Railway.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{10{\cdot}0}{5{\cdot}9} = 1{\cdot}7.$$

Fig. 17.

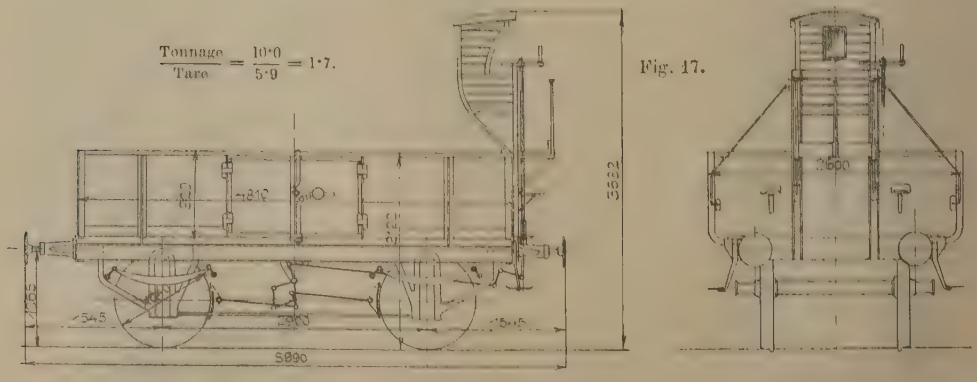


Fig. 17. — 26. Orleans Railway.

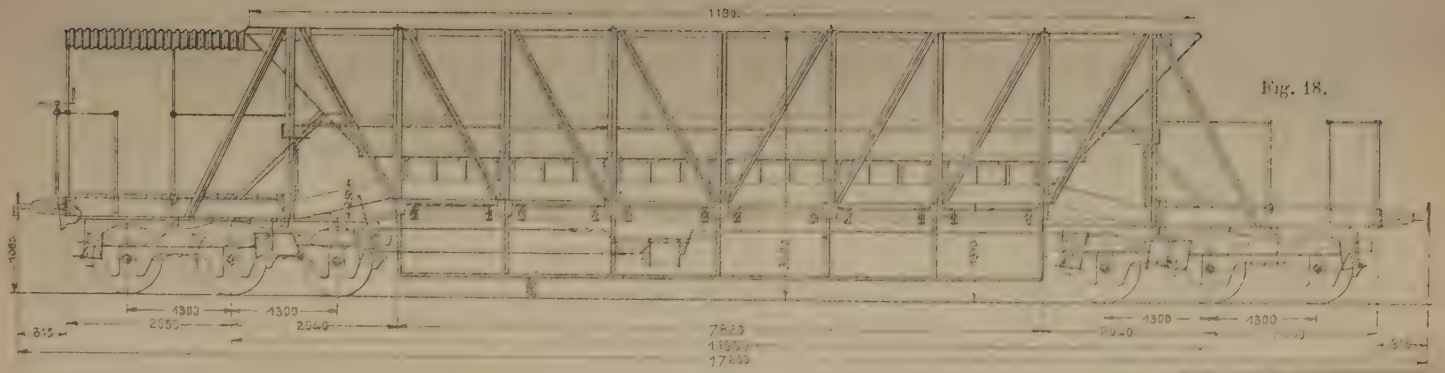


Fig. 18.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0}{24{\cdot}6} = 1{\cdot}62.$$

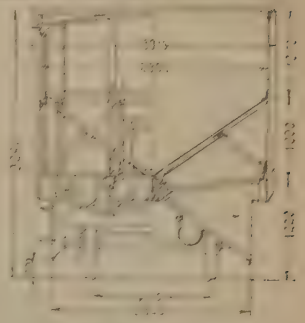


Fig. 18 (*continuation*).

Fig. 19.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{10{\cdot}0}{15{\cdot}5} = 0{\cdot}64.$$

Figs. 18 and 19. — 16. Hungarian State Railway.

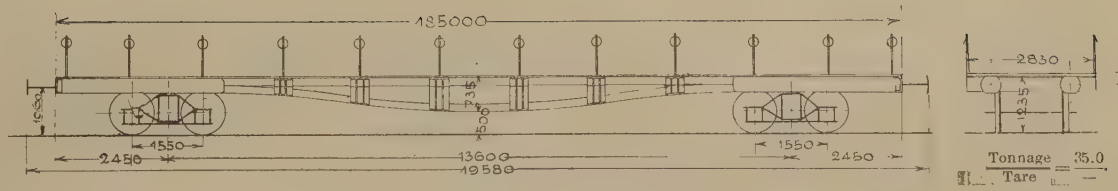


Fig. 20.

Fig. 20. — 17. Belgian State Railway.

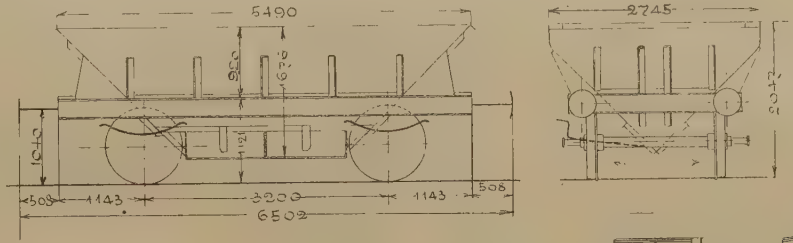


Fig. 22.

$\frac{\text{Tonnage}}{\text{Tare}} = \frac{15{\cdot}0}{7{\cdot}43} = 2{\cdot}0.$

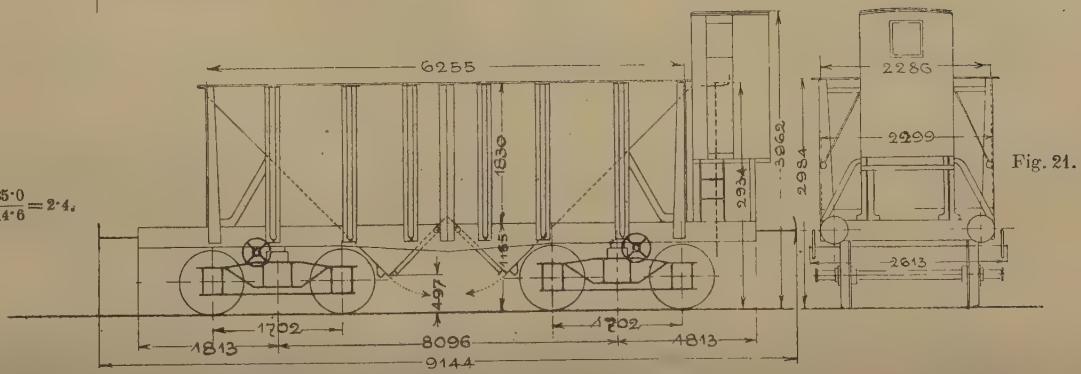


Fig. 21.

$\frac{\text{Tonnage}}{\text{Tare}} = \frac{35{\cdot}0}{14{\cdot}6} = 2{\cdot}4.$

Figs. 21 and 22. — 21. Great Southern of Spain Railway.

$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40}{17{\cdot}3} = 2{\cdot}34.$

Fig. 24.

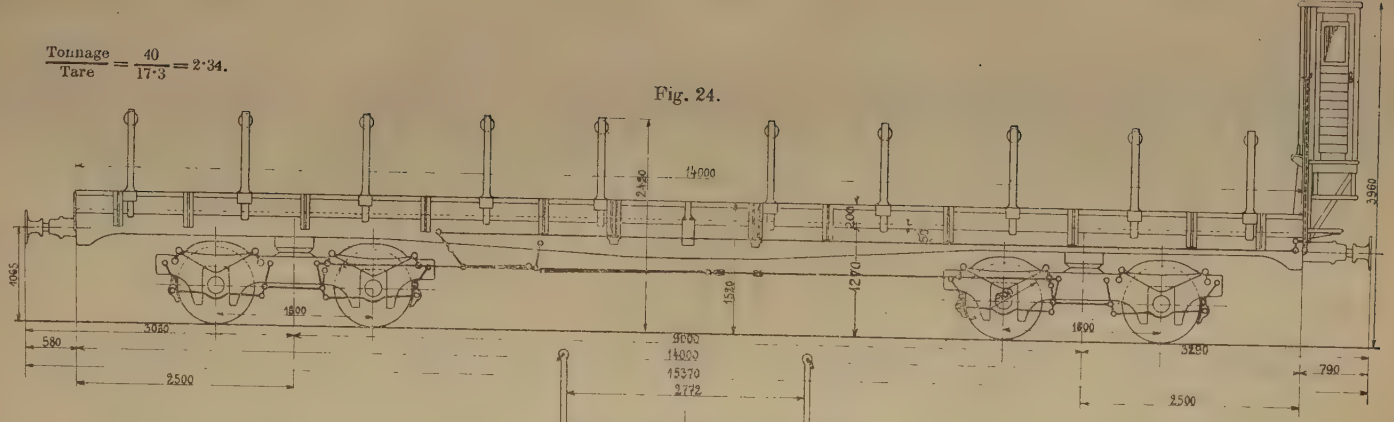


Fig. 24.

$\frac{\text{Tonnage}}{\text{Tare}} = \frac{50{\cdot}0}{16{\cdot}9} = 2{\cdot}96.$

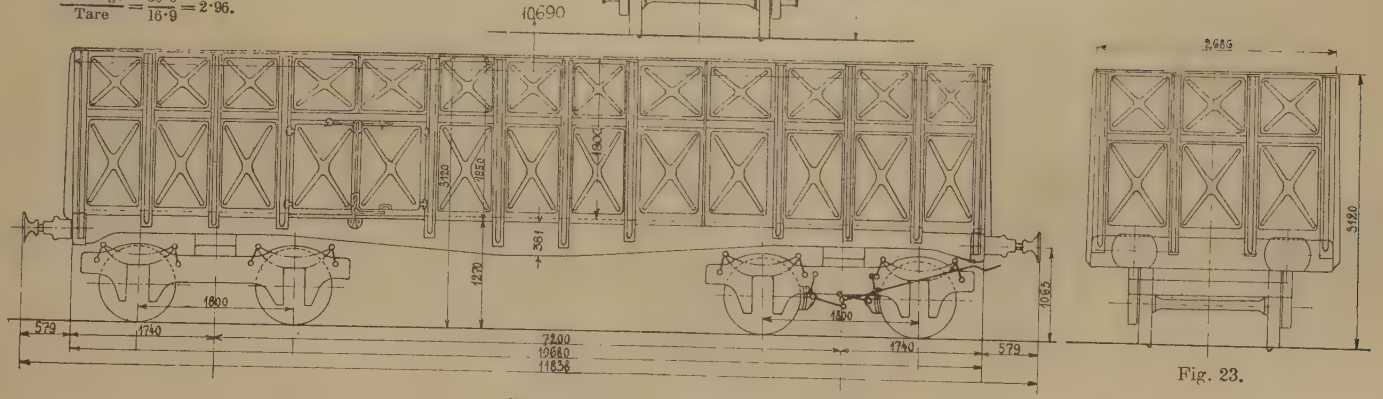
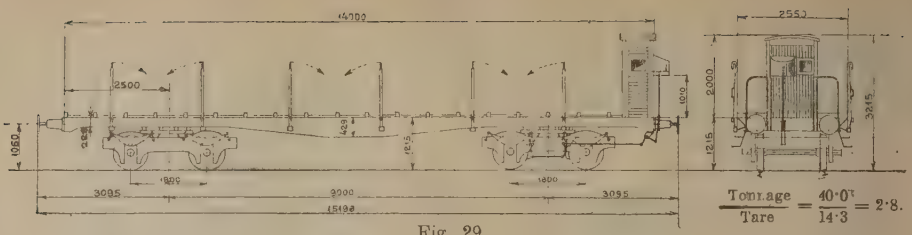


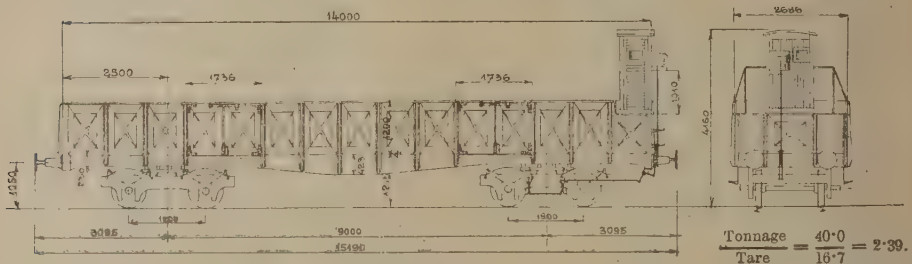
Fig. 23.

Figs. 23 and 24. — 25. Midi Railway.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0^{\text{T}}}{14{\cdot}3} = 2{\cdot}8.$$

Fig. 29.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0}{16{\cdot}7} = 2{\cdot}39.$$

Fig. 28.

Figs. 28 and 29. — 54. Italian State Railway.

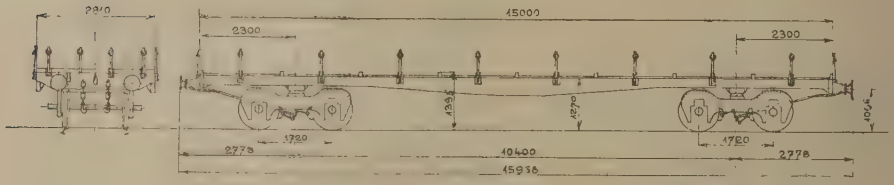
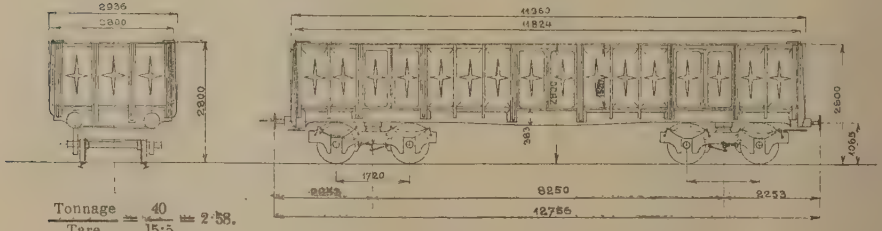


Fig. 26.

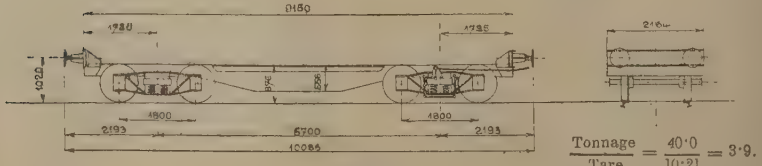
$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0}{14} = 2{\cdot}85.$$



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40}{15{\cdot}5} = 2{\cdot}58.$$

Fig. 25.

Figs. 25 and 26. — 27. French Northern Railway.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0}{10{\cdot}21} = 3{\cdot}9.$$

Fig. 27.

Fig. 27. — 28. Paris-Lyons-Mediterranean Railway.

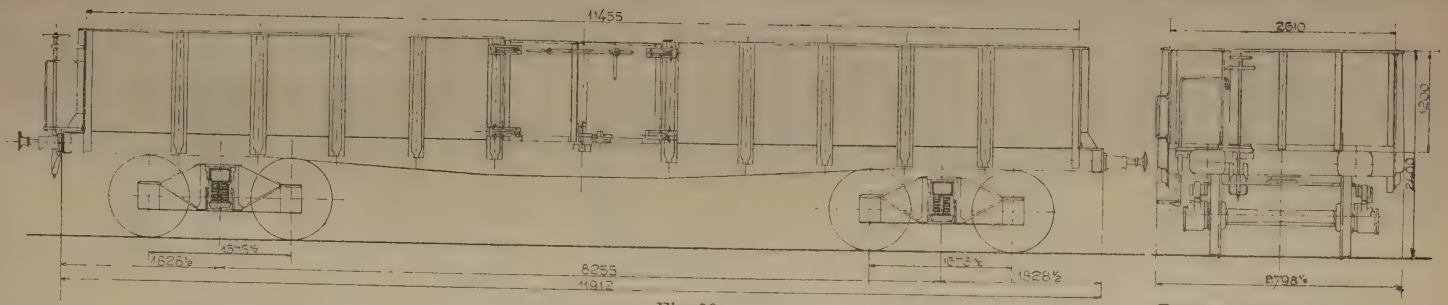


Fig. 30.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{30{\cdot}0}{15{\cdot}84} = 1{\cdot}89.$$

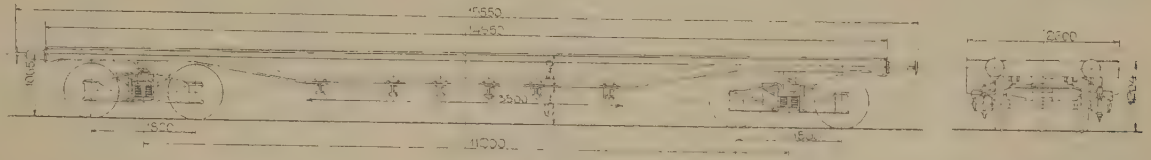


Fig. 31.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0}{19{\cdot}7} = 2{\cdot}03.$$

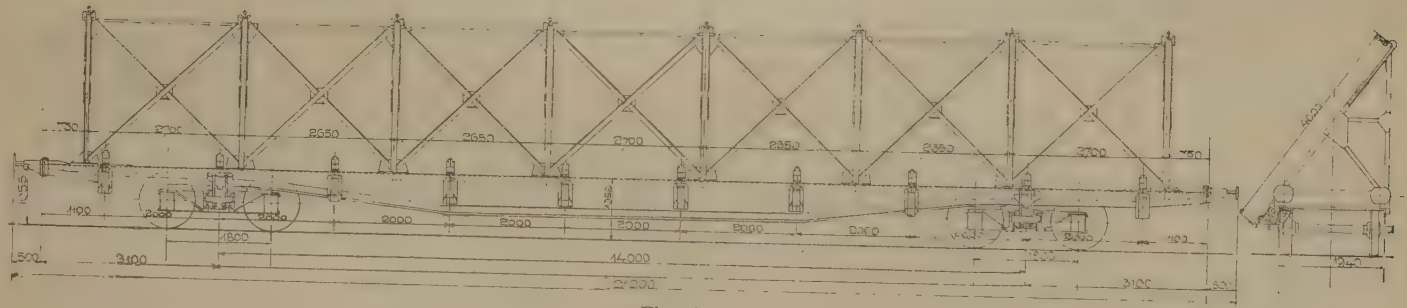


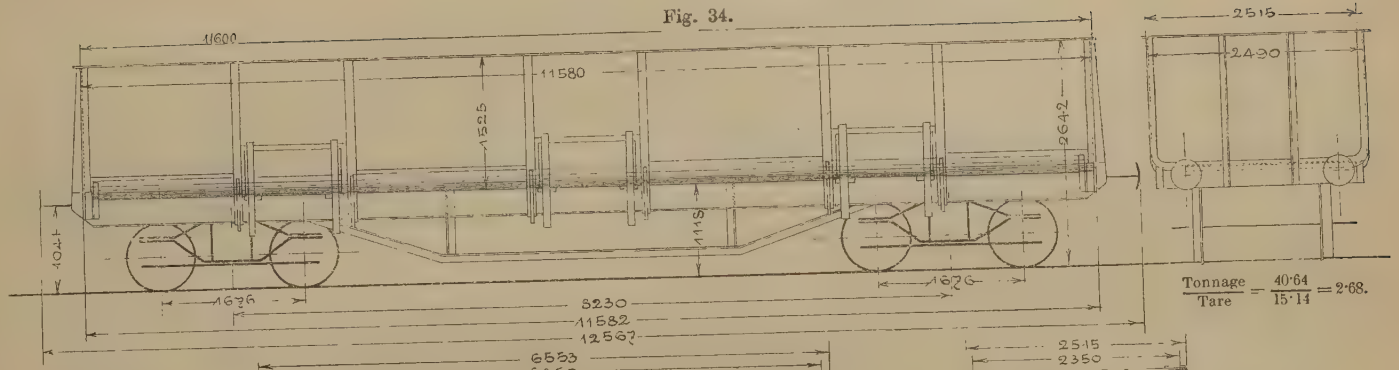
Fig. 32.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}0}{20{\cdot}9} = 1{\cdot}91.$$

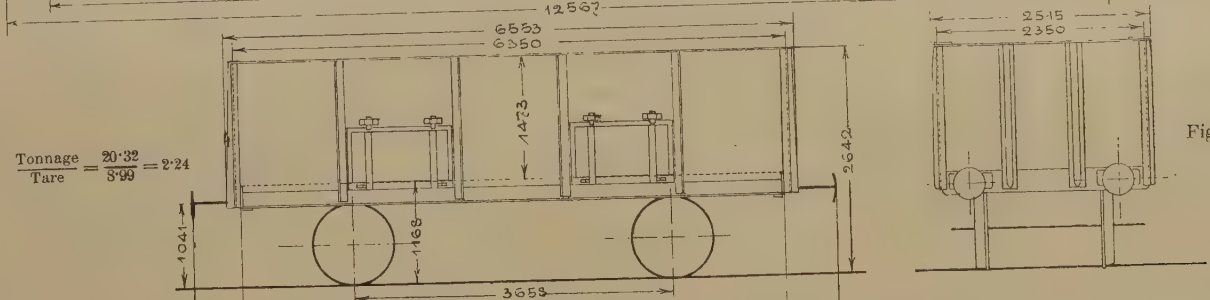
Figs. 30 to 32. — 28. Paris-Lyons-Mediterranean Railway.

Figs. 33 and 34. — 32. Great Central Railway.

Fig. 34.



$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}64}{15{\cdot}14} = 2{\cdot}68.$



$\frac{\text{Tonnage}}{\text{Tare}} = \frac{20{\cdot}32}{8{\cdot}99} = 2{\cdot}24$

Fig. 33.

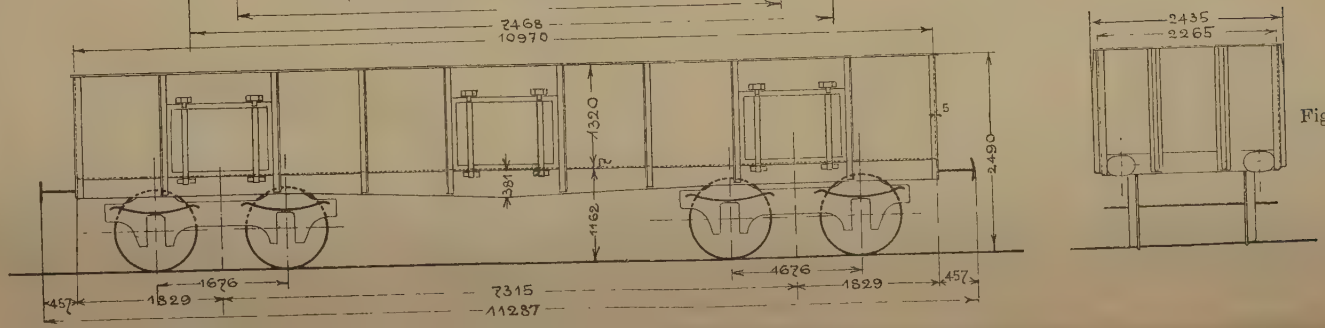


Fig. 35.

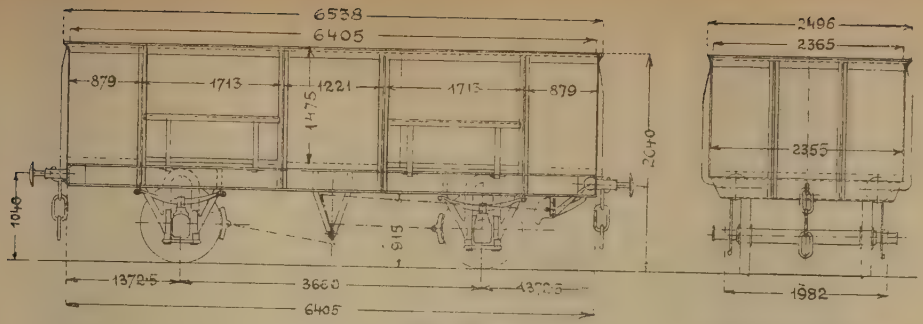


Fig. 39.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{20{\cdot}32}{8{\cdot}74} = 2{\cdot}32.$$

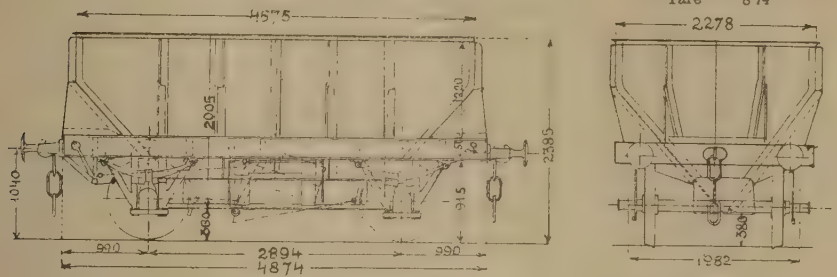


Fig. 38.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{20{\cdot}32}{7{\cdot}825} = 2{\cdot}59.$$

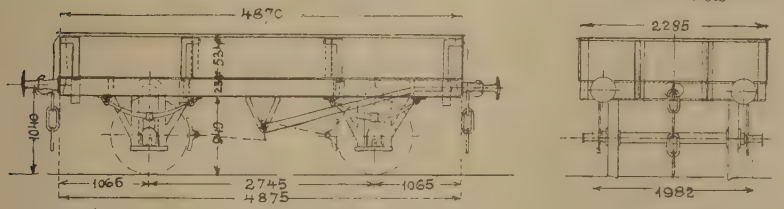


Fig. 36.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{8{\cdot}13}{5{\cdot}35} = 1{\cdot}52.$$

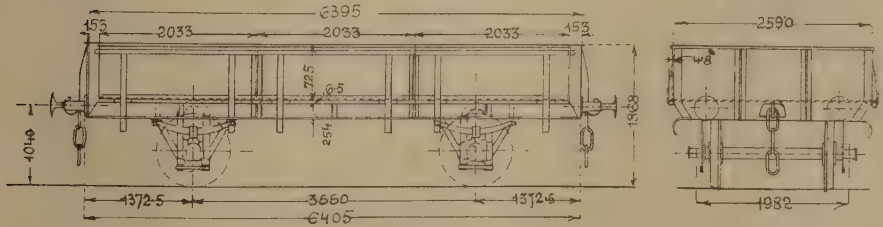


Fig. 37.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{20{\cdot}32}{8{\cdot}49} = 2{\cdot}4.$$

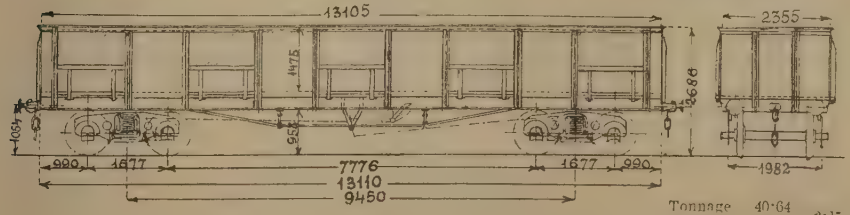


Fig. 40.

$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}64}{18{\cdot}95} = 2{\cdot}15$$

Figs. 36 to 40. — 34. Great Western Railway.

Fig. 43.

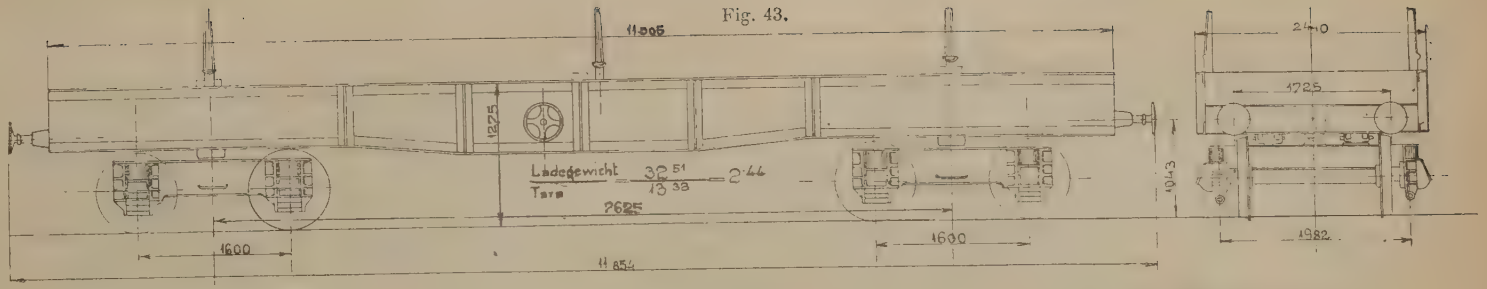
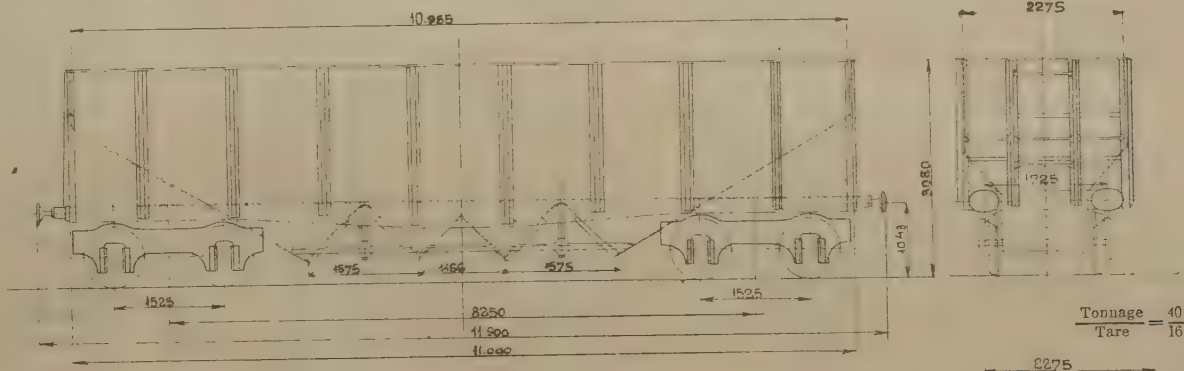
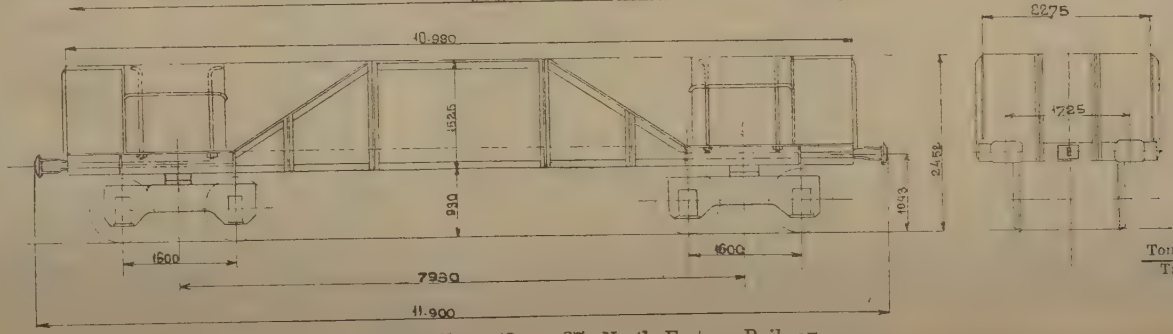


Fig. 41.



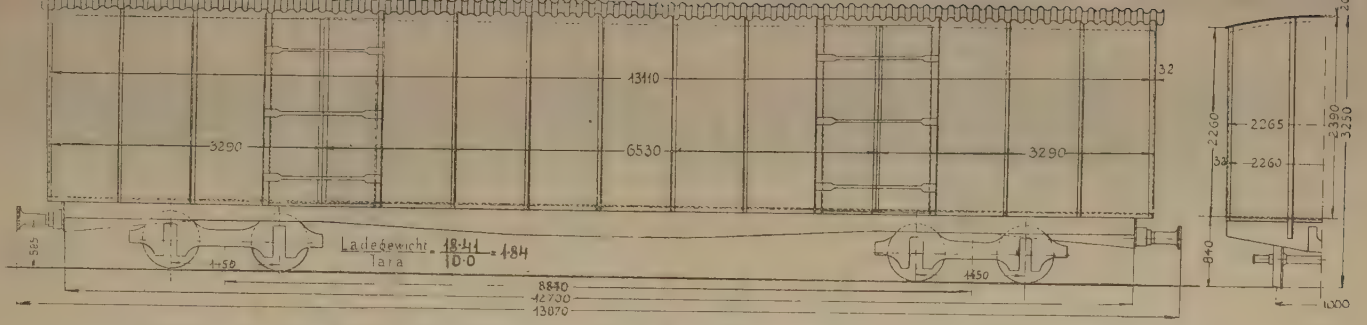
$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{40{\cdot}64}{16{\cdot}41} = 2{\cdot}48.$$

Fig. 42.



$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{30{\cdot}48}{13{\cdot}36} = 2{\cdot}27.$$

Figs. 41 to 43. — 37. North Eastern Railway.



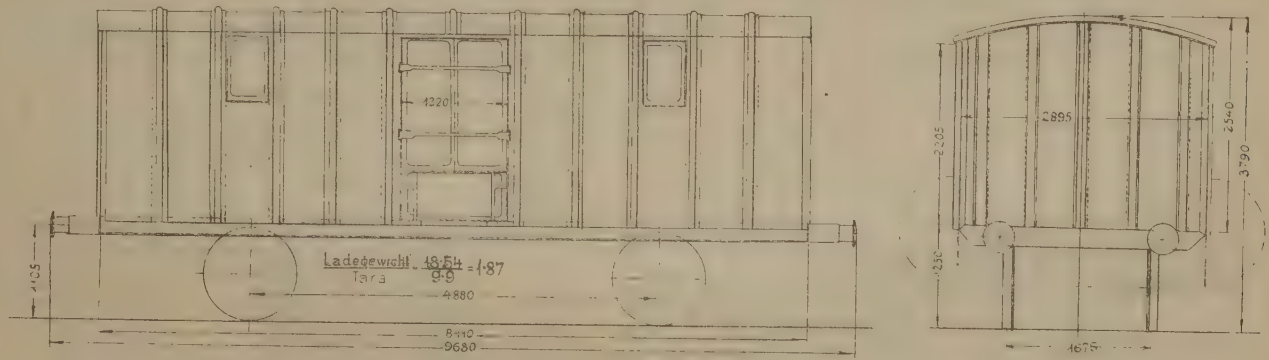


Fig. 44.

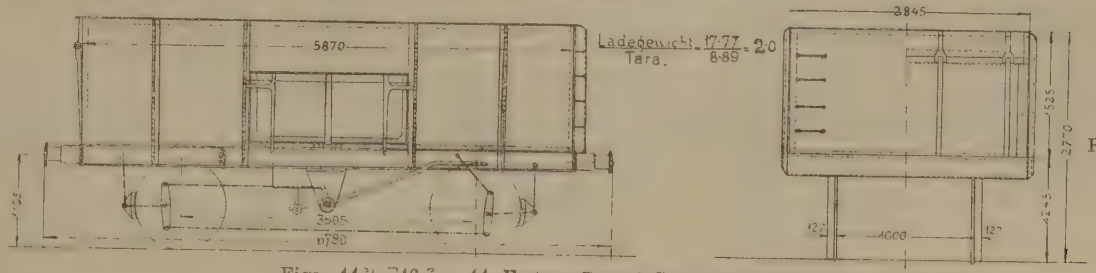
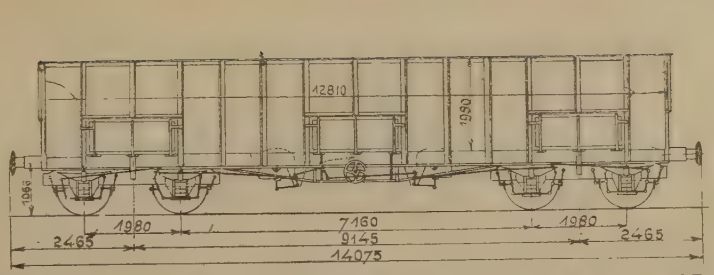


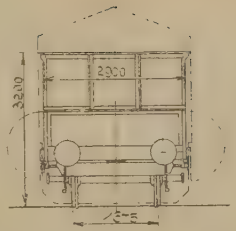
Fig. 45.

Figs. 44 to 46. — 44. Eastern Bengal State Railway.

Explanation of German terms : Ladegewicht = Tonnage. — Tara = Tare.

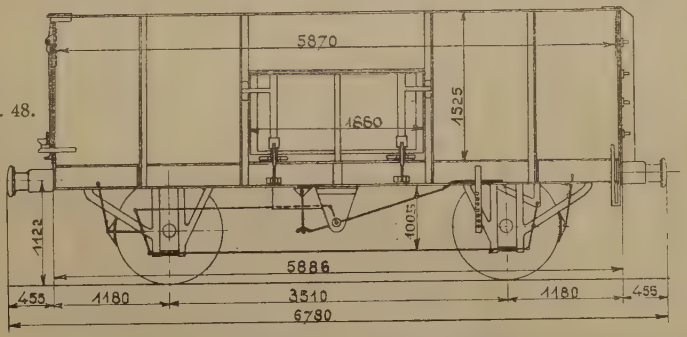
Fig. 49.

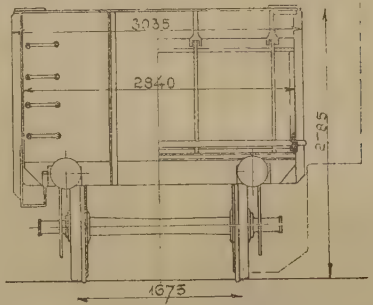




$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{43{\cdot}43}{21{\cdot}59} = 2{\cdot}0.$$

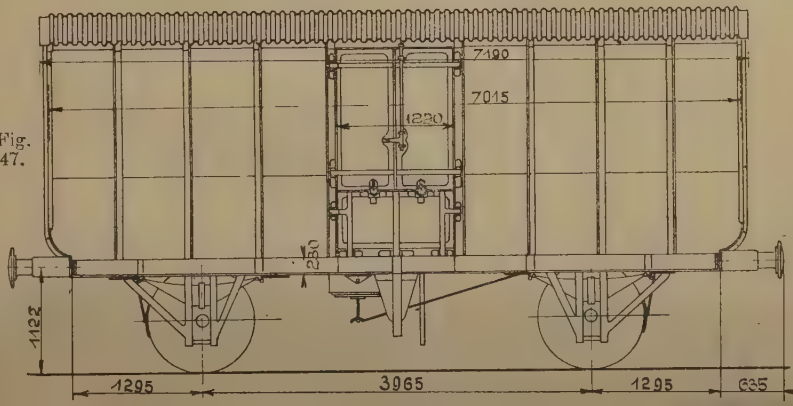
Fig. 48.

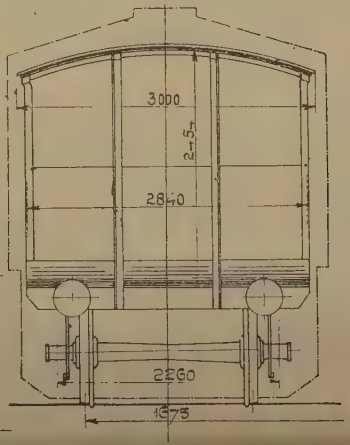




$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{23{\cdot}52}{9{\cdot}15} = 2{\cdot}57.$$

Fig. 47.





$$\frac{\text{Tonnage}}{\text{Tare}} = \frac{23{\cdot}52}{8{\cdot}99} = 2{\cdot}64.$$

Fig. 51.

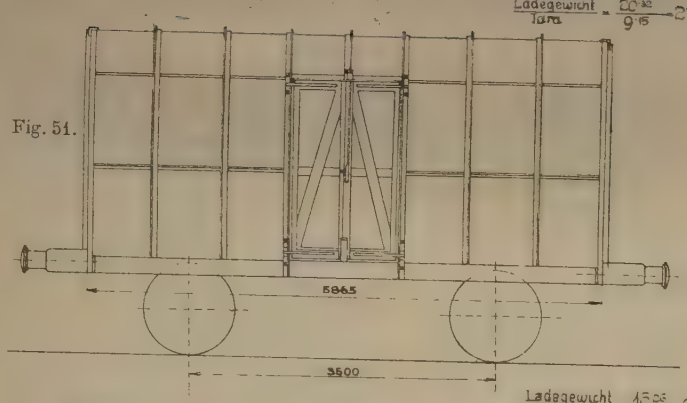


Fig. 50.

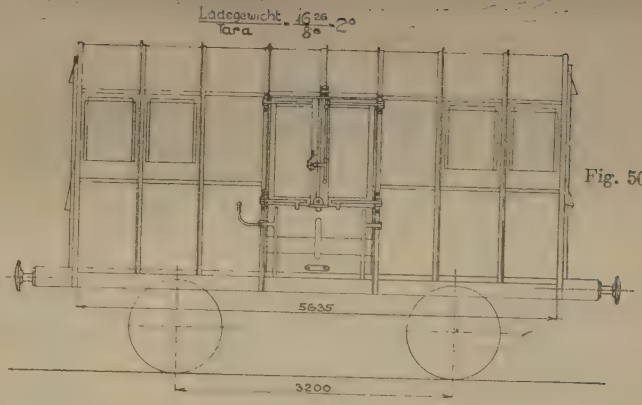


Fig. 52.

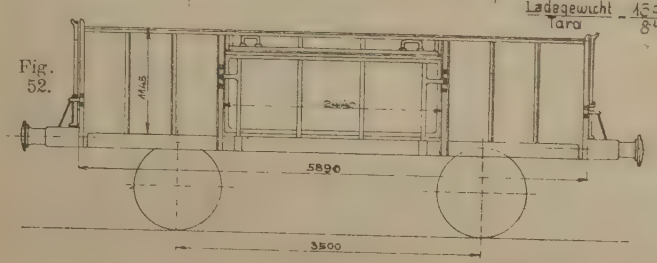


Fig. 53.

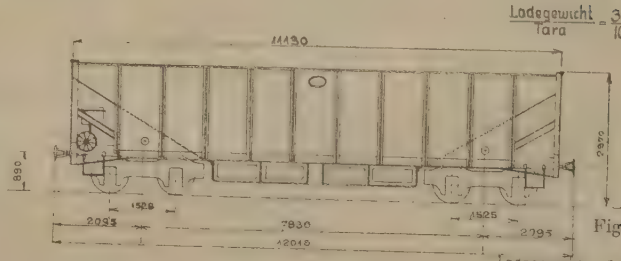
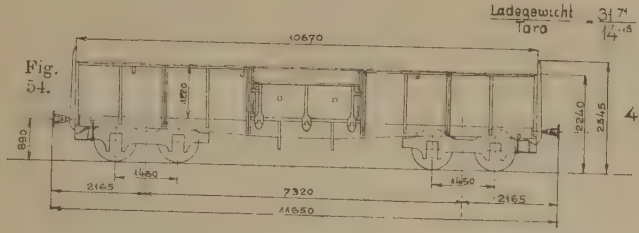
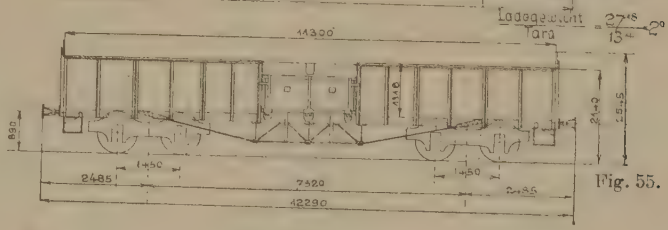


Fig. 54.



49.

Fig. 55.



Figs. 50 to 52. — 46. Great Indian Peninsula Railway.

Figs. 53 to 55. — 49. Central South Africa Government Railways.

Explanation of German terms : Ladegewicht = Tonnage. — Tara = Tare.

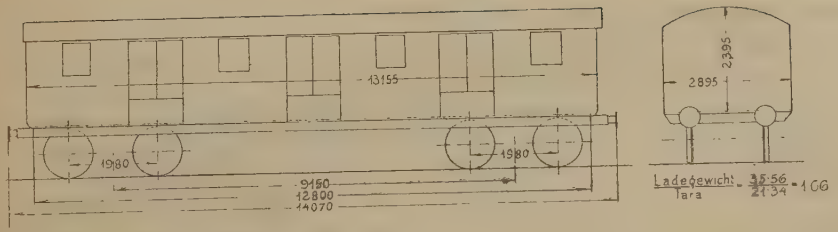


Fig. 58.

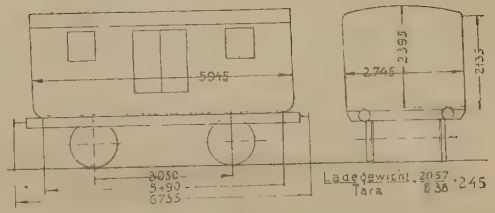


Fig. 56.

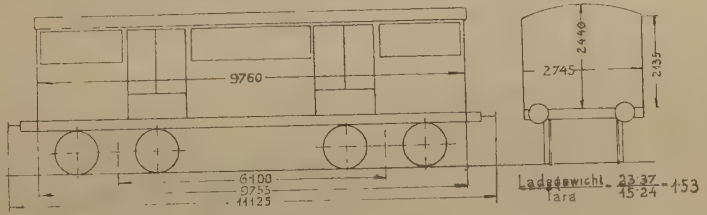


Fig. 57.

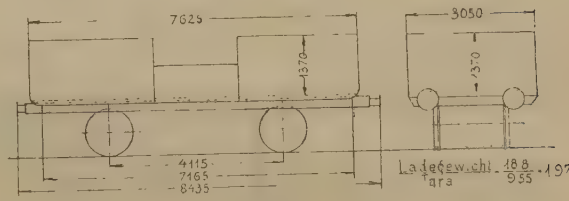


Fig. 61.

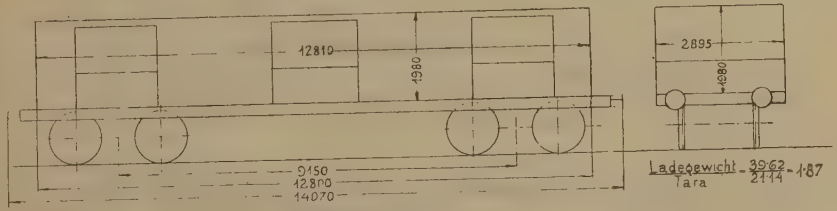


Fig. 63.

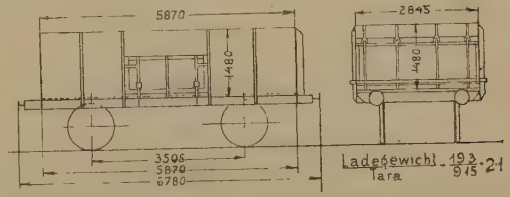


Fig. 62.

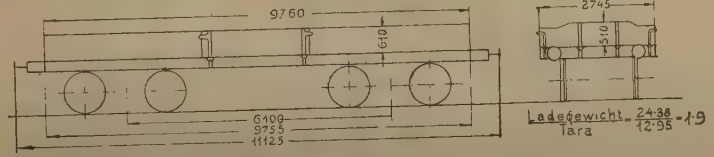


Fig. 60.

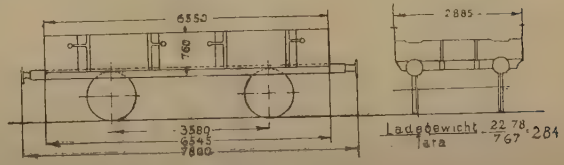
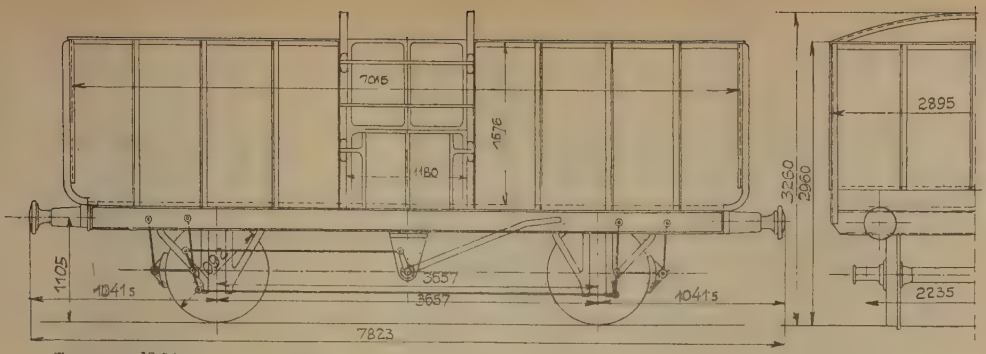


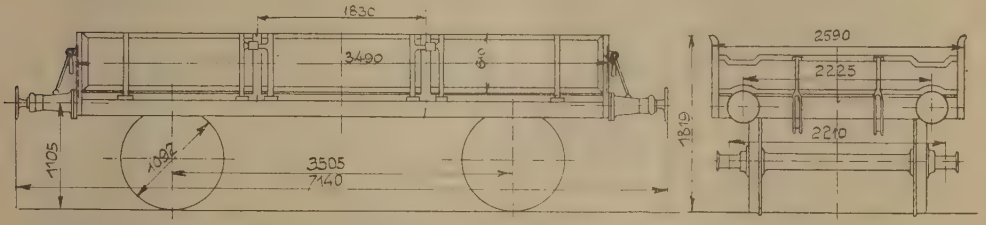
Fig. 59.

Figs. 56 to 63. — 47. Indian North Western.

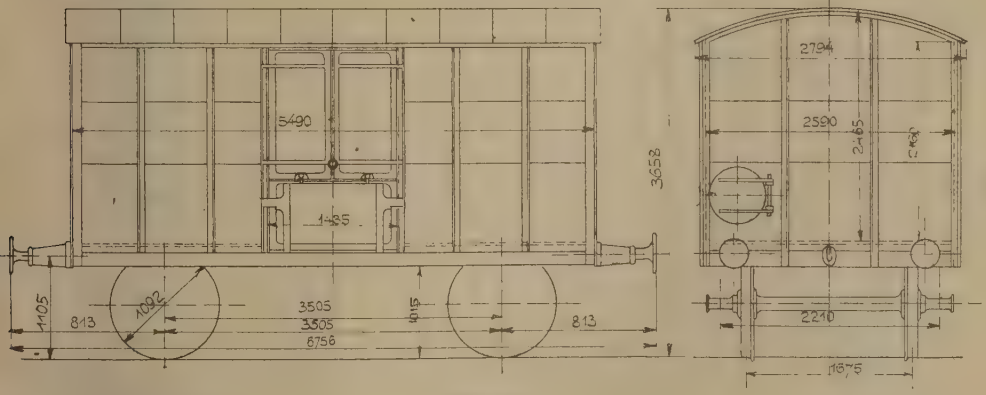
Explanation of German terms : Ladegewicht = Tonnage. — Tara = Tare.



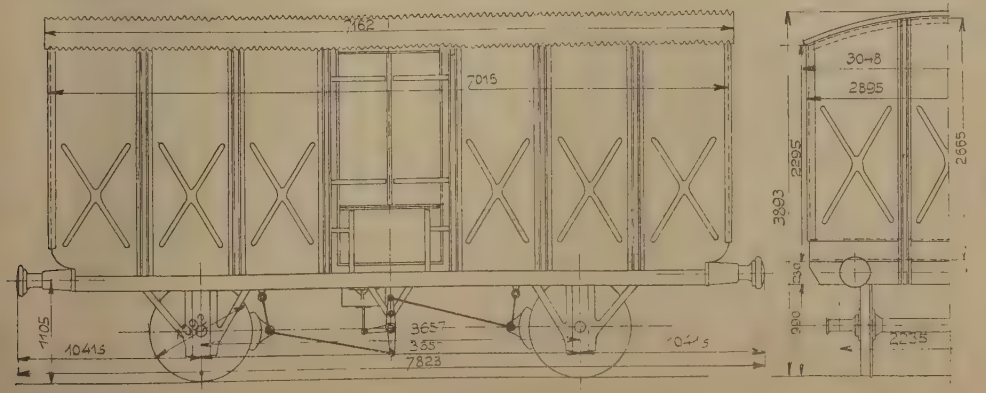
$\frac{\text{Tonnage}}{\text{Tare}} = \frac{18{\cdot}54}{9{\cdot}91} = 1{\cdot}88.$ Fig. 67.



$\frac{\text{Tonnage}}{\text{Tare}} = \frac{10{\cdot}16}{5{\cdot}69} = 1{\cdot}8.$ Fig. 66.



$\frac{\text{Tonnage}}{\text{Tare}} = \frac{11{\cdot}17}{7{\cdot}15} = 1{\cdot}56.$ Fig. 64.



$\frac{\text{Tonnage}}{\text{Tare}} = \frac{19{\cdot}92}{8{\cdot}64} = 2{\cdot}3.$ Fig. 65.

Figs. 64 to 67. — 48. Oudh & Rohilkhand State Railway.

Fig. 75.

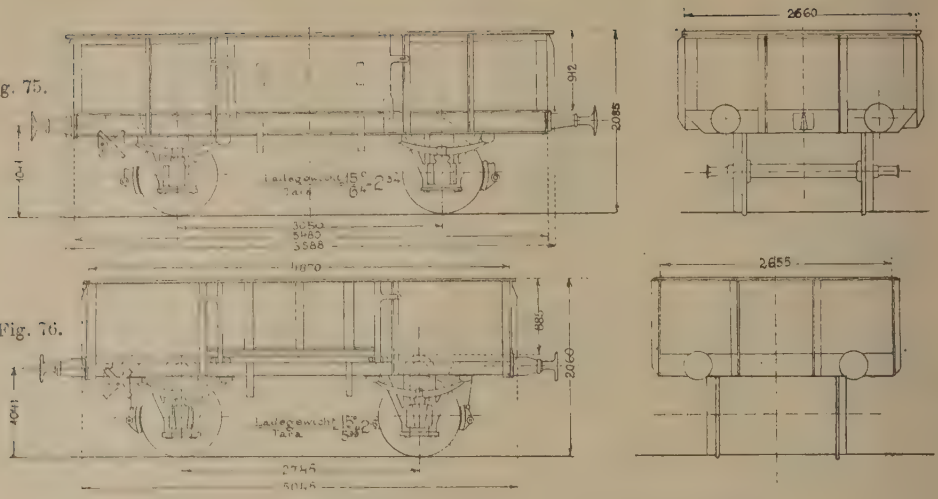


Fig. 76.

Figs. 75 and 76. — 52. New South Wales Government Railways.

Fig. 68.

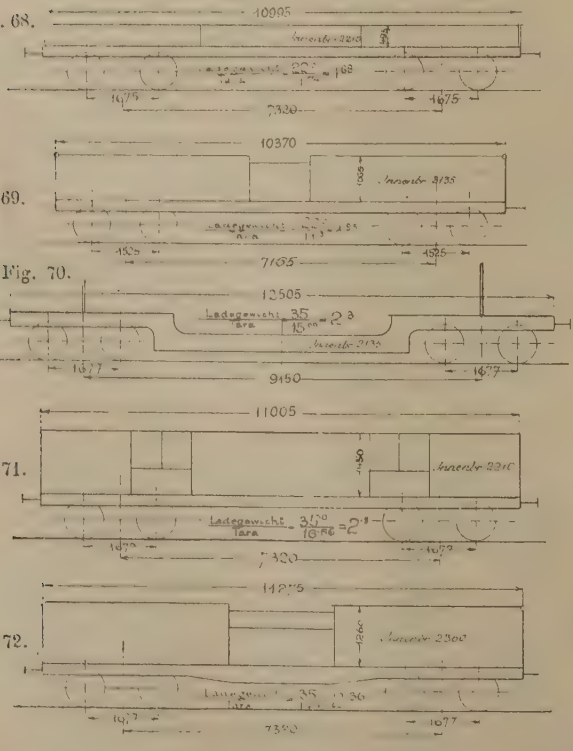


Fig. 69.

Fig. 70.

Fig. 71.

Fig. 72.

Figs. 68 to 72. — 51. Natal Government Railways.

Fig. 74.

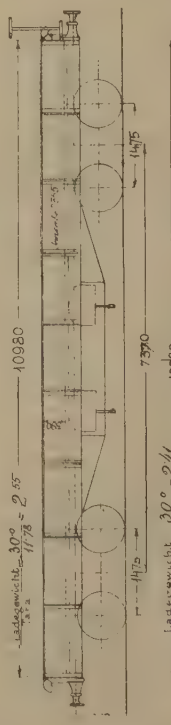
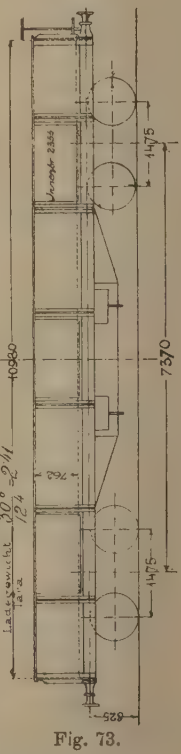


Fig. 73.



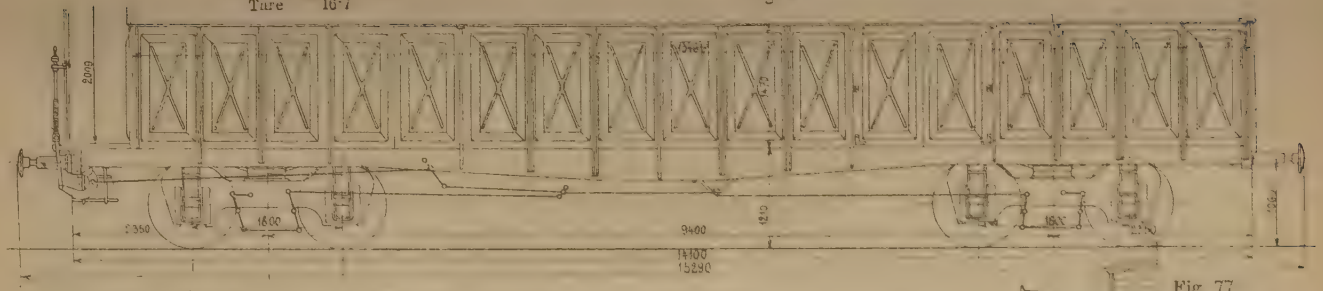
Figs. 73 and 74.
53. Tasmania Government Railways.

Explanation of German terms : Ladegewicht = Tonnage. — Tara = Tare. – Innerbr. = Width inside.

Fig. 77. — 58. Russian State Railways (Catherine line).

$\frac{\text{Tonnage}}{\text{Tare}} = \frac{37{\cdot}0}{16{\cdot}7} = 2{\cdot}2.$

Fig. 77.



$\frac{\text{Tonnage}}{\text{Tare}} = \frac{35}{10{\cdot}9} = 3{\cdot}2.$

Fig. 78. — 61. Swedish State Railways.

Fig. 78.

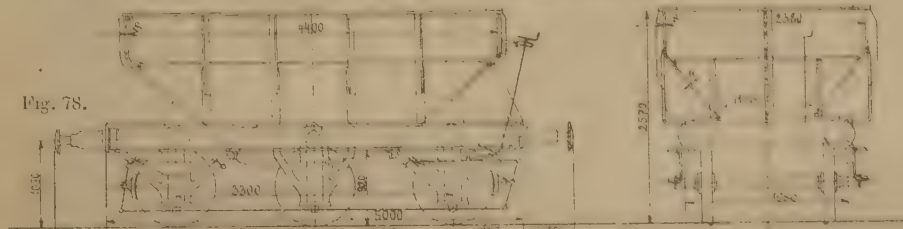
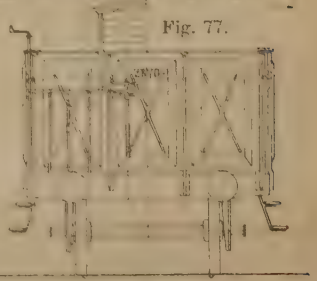
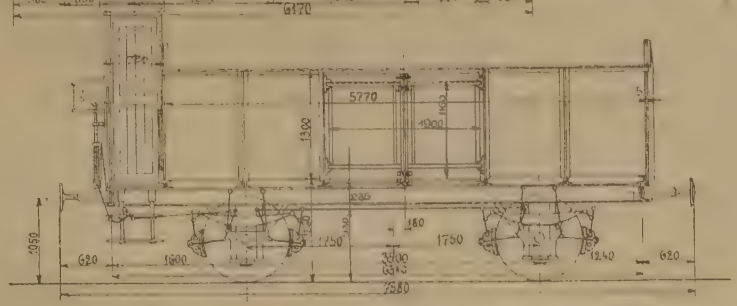


Fig. 77.





$\frac{\text{Tonnage}}{\text{Tare}} = \frac{15{\cdot}0}{8{\cdot}2} = 1{\cdot}95.$

Fig. 79. — 63. Swiss Federal Railways.

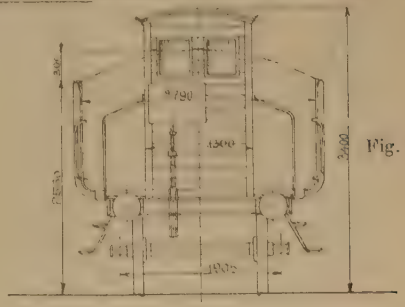


Fig. 79.

SECTIONAL DISCUSSION

Meeting held on 5 July 1910 (morning).

MR. GERSTNER, IN THE CHAIR.

The President. (In French.) — I call upon Mr. Kabodi to give a summary of the report drawn up Mr. Szlabey, who is unable to attend.

Mr. Kabodi, Hungarian State Railway. (In German.) — Owing to Mr. Szlabey's absence, I am entrusted with the duty of giving the meeting a short summary relating to subject V, littera *A*.

Unfortunately the greater number of the administrations belonging to the Congress did not send any answers to the list of questions sent to them, so that my summary of the subject in question can in no way be complete.

In considering the first part of the question : " Use of steel in the construction of locomotives and rolling stock ", the first point which arises is the meaning to be attached to the term " steel ".

As there are very great differences in the nomenclature of the materials, it was in the first place necessary to state that the term steel should only be applied to metal having an ultimate tensile strength of more than 44 kilograms per square millimetre (62,580 lb. per square inch). Moreover, in drawing up the list of questions, there was no desire to consider the use of a metal of poorer quality, for in the 20th century, as an English administration very justly remarks in its answers, there is hardly a railway which does not extensively use steel or iron in the construction of its rolling stock. Metal having an ultimate tensile strength of less than 44 kilograms per square millimetre, can accordingly no longer be designated as steel, if we want to observe the technological accuracy necessary; it is advisable to call it ingot iron, and hence, it is outside the scope of our subject.

Similarly, we have to be silent about various parts of the rolling stock, such as axles, tires, springs, draw and buffing gear, boilers, etc., which form the subject of separate reports under the heading of littera *B*.

Now that this is understood, we will in the first place remark that the steels used by the different administrations differ radically in their properties. We can, however, classify them into two groups :

1° Forged or rolled Martin-Siemens steel;

*

2° Steel castings made of Martin steel.

The former is generally used for parts subject to much fatigue and wear and tear, which for reasons of safety must be made of a tough and strong metal, and which owing to simplicity of form can be easily and cheaply produced by forging methods; for instance, brake shafts and brake-shaft bearings, bolts, boxes, cranks, crank pins, coupling and connecting rods, valve rods and piston rods, frame plates, etc., of locomotives; bogie pivots, supports, etc., of passenger carriages and goods wagons.

Steel castings made of Martin steel are used for those parts which must be very strong and safe, and also must have a long life, but which are of a complicated shape, so that it would be difficult and costly to produce them by forging methods (axle-boxes, hornplates, brake levers, brake-shaft bearings, pistons, crossheads, frame supporting reversing gear, framing and cross framing, spring hangers, centre bearings of bogies, brackets, etc., of locomotives; axle-guards, centre pin sockets of bogies, body queen posts, sundry bearings, spring hangers, door hooks and shacklers, buffer boxes, wheel centres, wheel disks, brackets, of passenger carriages and goods wagons). The strength of these steels varies; it exceeds 44 kilograms per square millimetre (62,580 lb. per square inch) in the case of :

1° Coupling and connecting rods in Germany, Great Britain and Switzerland;

2° Piston roads and valve rods, in the same countries;

3° Cranks and crank pins, in Germany and South Africa;

4° Frame plates of locomotives, in Spain, Great Britain, South Africa, Italy and Sweden.

The steel is everywhere required to be homogeneous; bending tests, cold and after quenching, impact tests and phosphorus content also appear in the specifications of many administrations.

Steel castings for wheel centres : strength 37 to 45, 40 to 60 kilograms per square millimetre (52,625 to 64,000, 56,890 to 85,340 lb. per square inch). Steel castings used for axle-boxes and hornplates have a greater strength than in the case of wheel centres. Locomotive frames made of steel castings are used by no railway outside America; this is quite a surprising fact. Steel castings are, however, used in some cases for bogie frames, in Denmark, Algiers, India and Sweden.

The greater strength, the better wear and the longer life of the parts made of it are the reasons for the use of steel. Another reason is that wrought or puddled iron is becoming rarer and rarer and is now made only at few works in Europe. Finally, the progress in metallurgical science makes it possible to produce compact steel castings, free from blowholes, and this has led to increased use of them. Steel castings have entirely replaced cast iron; on the other hand, when articles are wanted in large quantities, steel castings are cheaper than wrought iron. Some administrations have been using them for twenty-five to thirty years; others have only been using them for a very short time. Their gradual adoption is due not only to the state of development of the iron industry in the different countries, but also to the heavier work which rolling stock now has to do. The results given by steel castings have as

a rule been very satisfactory, both as regards safety, life and need of repair, and as regards lower cost of maintenance, which can be set off against greater prime cost. Another advantage of steel castings is the possibility of reducing the weight of parts by reducing the dimensions and improving the shape.. Disadvantages : cracks are produced in wheel centres on account of insufficient annealing. The Dutch State Railway records cases of the fracture of wheel disks which were steel castings; there have also been cases of fracture of bogie frames and spring hangers on that railway, which now no longer uses steel castings for these parts. Other disadvantages of steel castings are that they are more difficult to machine and that their prime cost is higher.

The following is the conclusion I propose on this point :

Steel having an ultimate tensile strength of over 44 kilograms per square millimetre (62,580 lb. per square inch) is used, instead of the wrought iron formerly used everywhere, only by a few of the administrations, only for a few of the locomotive parts in question, for instance for connecting and coupling rods, piston and valve rods, cranks and crank pins, and locomotive frames. As general substitute for wrought iron, mild steel or ingot iron is used, having an ultimate tensile strength of 33 to 44 kilograms per square millimetre (46,935 to 62,580 lb. per square inch).

Steel castings are in many cases used as a substitute for wrought iron in the case of parts which are difficult to make and are of complicated shape. Steel castings are very generally used as a substitute for cast iron in the case of parts, which are subjected to much fatigue and wear and tear, and more exposed to damage; their use in such cases results in increased security.

Second point : " carriages and wagons made entirely of steel or iron. "

Of the two hundred and fifty administrations, adherent to the Congress, to whom Mr. Szlabey sent his detailed list of questions, only thirty-seven, or 15 per cent, stated that they had goods wagons made entirely of steel, that is to say, wagons of which the running gear and the underframe, as well as the body frame and the body are entirely of steel, no wood being used, while twenty-nine administrations, or 12 per cent, stated that they had no wagons of this kind.

The definite wording of the question excluded, *ab initio*, all the wagons of mixed construction, that is wagons with metal underframe and running gear, and with wooden body and lining.

Owing to the limited information received, the report was unable to deal at sufficient length and detail with this very important railway question, and it is advisable to emphasize that the conclusions drawn in the report may require modification as regards the administrations which it was not possible to take into consideration.

According to the unanimous report of the administrations which sent answers to the list of questions, and among which are included the greatest railway systems on the Continent, no passenger carriages made wholly of iron exist on any railway, America excepted; mixed construction is used nearly exclusively in Europe for modern carriages.

This state of affairs is all the more remarkable as on American railways a

considerable number of carriages made wholly of metal exist; and according to the information collected, these carriages offer sundry advantages.

The reasons for this remarkable state of affairs are probably : the construction of these carriages involves considerable difficulties; an increase of weight is inevitable; finally, as regards passenger stock, questions of strength and of durability are not the only ones which arise, but one also has to take into consideration smooth and silent running, protection against heat and cold, great elasticity and, consequently, greater safety against violent damage, and also any existing æsthetic considerations. But, on the other hand, it must also be stated, that when the body is made of wood and combustible substances are used, there is risk from fire. Serious accidents, unfortunately inevitable in railway work, which have lately occurred, have often been accompanied by fires the effect of which has been far more disastrous, as regards loss of life and damage to property, than collisions or even derailments.

I therefore think that nobody will disagree with me if I state that intelligent car builders will in future consider more carefully the question of carriages made entirely of metal, eliminating as completely as possible any combustible materials; and that we have been wrong in not paying, up till now, greater attention to the experiments made in America. It is true that some underground railways in Europe use carriages made wholly of metal. But this has been done because it was necessary to suit the cross-section of the carriage to that of the railway, and utilize the available space as much as possible, that is to say occupy as little space as possible by the body.

Another remarkable fact is that the number of wagons made wholly of iron is very small compared with the total stock on railways (America excluded), and represents a proportion of 10 per cent.

The total number of iron wagons given in the answers amounts to 94,850; of these 29,505 or 31 per cent are in Europe and 65,345 or 69 per cent are in other countries (India, South Africa, Australia). We observe the remarkable fact that in Europe iron wagons form the smallest proportion of the total goods stock, and that all these wagons, except the tank trucks, gas-holder trucks, and the gunpowder vans used on some British railways, are open wagons. On the other hand, the railways in the oversea countries use iron for nearly all their goods stock. The reason is no doubt that climatic conditions and the scarcity of timber in those countries, which are to a great extent tropical, make it impossible to use body frames and walls of wood; and that those countries, where there are as yet few works, procure these wagons in pieces put together subsequently, a method of carriage which is more practicable in the case of iron than in that of wood.

The designs of the iron wagons vary considerably and depend chiefly on local conditions and on the class of goods which are to be carried. In general, the different types of wagons resemble each other in that the iron underframe has on it a body frame with sides made of flat or corrugated steel plate, or of plate pressed into shape. As regards the floors, steel plate is also used, and often wooden

planks. On many railways, the ends, and sometimes also the sides, of high and of low trucks can often be raised or lowered or taken off.

Wagons made wholly of iron, to hold 10 to 20 tons, were first used in 1866 on some European railways, for instance on the Hungarian State Railway; but it is only since 1880 that wagons of this kind have been built in any numbers. Several large European railways (French, Russian and English) have only been using wagons of this kind for a very short time, and that only as an experiment. But the construction of wagons with three and four axles, to take 25 to 43 tons (24·6 to 42·3 English tons), only dates back to the beginning of this century; particularly as regards self-discharging wagons. The reasons which led the administrations to use iron only in the construction of their goods wagons were of several kinds. In the first place, certain goods were to be carried in specially suitable wagons, and iron is better for this purpose than wood. Then it was desired to increase the capacity, while reducing the tare; to simplify the construction, to increase the strength and the life of the rolling stock. Finally, the design of certain types of wagons, for instance sef-discharging wagons, and the exceptional tonnage of certain types made it necessary to use iron exclusively.

A question of great importance as regards the economic operation of railways is diminution of the tare, combined with increase of tonnage. Several administrations have in fact obtained results which are very favourable from this point of view. Thus there are the self-discharging wagons, with three axles, of the Swedish State Railway, which take 35 tons (34·4 English tons) and only have a tare of 10·9 tons (10·7 English tons), a ratio of 3·2 : 1; and the self-discharging wagons, with four axles, of the Great Central Railway and of the North Eastern Railway, which take 40 tons, and have tares of 15·1 and 16·4 tons respectively, thus giving ratios of 2·68 : 1 and 2·4 : 1

Unfortunately we have no reliable data available to enable us to make a proper comparison between wagons made wholly of iron with wagons made of wood or of wood and iron; for wagons of the same type and the same tonnage do not as a rule exist. Nor does the information supplied give any definite answer about this point, for some administrations report favourably about iron wagons, while other administrations do the reverse. The same remark applies to the cost of construction of wagons of iron, of wood, or of iron and wood; this as we know varies with the existing market prices at the time of construction, with the industrial development of the country and the place of production, and is sometimes higher and sometimes lower for wagons of one and the same type.

However this may be, one can, as regards the cost of construction and the tare, lay down the general principle that on railways where more importance is attached to a long life and a low cost of maintenance, and where consequently the wagons are made stronger, the wagons will be heavier and cost more; but, on the other hand, special design and equipment (self-discharging wagons, hand brake, automatic brake, etc.) will have a great influence on the cost and on the tare of the wagons.

Another factor which has a great influence on the tare is the thickness of plate selected, which varies from 4 to 8 millimetres ($^5/_{32}$ to $^5/_{16}$ inch); the use of pressed plates, which can be made thinner while having the same strength, and especially the replacement, becoming more and more general, of rolled sections and of forgings by pressed plates and frames, also contribute very materially to the reduction of the tare. The replacement of cast iron by steel castings also gives satisfactory results.

The actual results obtained up to the present have led a few administrations to recognize unreservedly that the exclusive use of iron or steel for the construction of goods wagons makes it possible not only to increase the tonnage materially, but is also attended with so many other advantages, that it appears desirable to extend their use. These advantages are: increased strength in case of collisions and violent treatment, greater safety when in use, a lower cost of maintenance, a longer life, and finally less risk from fire.

Moreover, wooden wagons cannot be used for certain classes of goods, for instance liquids, manure, clinkers, lime, etc. Similarly self-discharging wagons can only be made of iron.

As against these appreciable advantages, certain administrations, for instance the Prussian State, the Bavarian State, the Hungarian State, the Russian Catherine II Railway, the Midland Railway, the Great Central Railway, bring forward the following disadvantages: high cost of maintenance, long time required for repairs, oxidation of the walls and floor in damp climates; it is indispensable to retard corrosion, by frequent painting with lead paint and with tar. Moreover, it is advisable to round off edges and corners, particularly at the bottom, and to line the floor with wood, even when the body is made of steel.

Some of the administrations think that iron wagons are not suitable for carrying goods, such as salt, which have a corrosive action on iron. Finally, certain administrations cannot yet give any opinion as to the advantages and disadvantages of iron wagons, as they have only adopted them quite recently.

In consequence of the results obtained, most of the administrations propose in the future to build certain types of wagons wholly of steel or of iron, but to have a wooden lining to the floor. Other administrations, for instance the Prussian State, the French Northern, the Hungarian State, the Paris-Lyons-Mediterranean, do not intend to use iron wagons in future except for goods for which wooden wagons cannot be used, for instance tank trucks, gas-holder trucks, manure wagons; or when the type of wagon excludes the use of wood, for instance self-discharging wagons. These administrations think it better, in the case of covered wagons, high-sided wagons and low wagons, to have only the body frame made of iron, with walls and floor of wood.

The railways in oversea countries intend to continue to use covered and high-sided wagons made wholly of iron.

Taking into consideration the very different requirements the railways of the world have to meet, in consequence of the variations in the civilization, the geographical, industrial and climatic conditions, it is impossible to lay down general principles concerning the most suitable design

of the goods wagons and the best material for their construction. But everywhere there is a tendency to use for different classes of traffic, wagons specially designed for the purpose, and, on the other hand, to increase the tonnage, while at the same time reducing the tare as far as is practicable, without compromising strength and durability.

This remark applies specially to bulk goods, particularly to coal, lime ore, etc.; in order to reduce the cost of carriage and of handling these goods, iron self-discharging wagons were introduced and the tonnage increased up to 40 tons, and this practice is being continually extended; the results obtained so far have been exceedingly satisfactory.

Modern goods stock is accordingly characterized by greater tonnage, by the use of self-discharging devices, by reduction of the tare, by reducing the sections and dimensions by using pressed plate and steel castings. Finally, attention must be paid in the future to the quick loading and unloading of goods wagons, by improving the station installations, for instance by having shoots, etc.

The information obtained leads to the following conclusions :

1° Passenger carriages made wholly of steel and iron have up till now not been used at all, or only in some very special cases;

2° Goods wagons made wholly of steel and iron are only used on European railways to a rather small extent; on railways in colonies in other continents, they are, however, used extensively or nearly exclusively;

3° Steel and iron are suitable not only for the underframe and the running gear, but also for the whole body of those open goods wagons, which are to have a large tonnage and as low a tare as possible, which are accordingly intended for the carriage of very large or very heavy articles, of liquids, of manure, of lime, and also and especially of bulk goods, such as coal, ore, ballast, beet-roots, etc., and, finally, for that of those wagons of special design which are intended to discharge goods in bulk, particularly coal, automatically, and which are known as self-discharging wagons.

On the other hand, in Europe, the exclusive use of steel and iron for making bodies is only usual in the case of those covered goods wagons which are specially for the carriage of dangerous and explosive goods;

4° It is advisable, even in the case of the open and covered goods wagons built wholly of steel and iron, to use wood for the flooring instead of metal plates, and to round the bottom corners;

5° Replacing the rolled girders, plates and sections and the forged parts, by pressed girders, plates and parts and by steel castings, makes it possible to reduce the tare and increase the durability and strength of the wagons;

6° In order to prevent corrosion, care must be taken to provide for repeated renewal of the paint.

The President. (In French.) — We will now take Mr. Crawford's report. I call upon Mr. Crawford to give a summary of his report.

Mr. Crawford, *reporter.* — Steel has been used extensively in the construction of locomotives, especially in the last ten years. Tubes are made of steel, and very good results have been obtained with safe ends made of steel for boiler tubes. Tubes having the steel safe ends can be caulked more frequently than those having iron safe ends before it is necessary to renew the tube on account of the beads becoming

defective. Attention is drawn particularly to the desirability of giving more care to the specifications and manufacture of locomotive tires, as with the heavy equipment now in service the wear is rapid and the frequent renewal and turning of the tires expensive.

As to the use of steel in passenger and freight car construction, I refer you to the several engravings and tabulated statements in my report as an indication of its extensive use. For example : the Pennsylvania Railroad system has 74,466 freight cars of all-steel construction and 53,662 freight cars with steel underframes. The most complete information regarding the cost of maintaining steel cars as compared with the cost of maintaining cars of wooden construction is that furnished by the Bessemer & Lake Erie Railroad, which company has kept comparative statistics of the maintenance cost for several years. These data are shown on page 53 of my report (1). The comparison has been favourable to the steel cars. It will be interesting to note from the table on page 54 of the report that during a twelve-year period, during which time an average number of about 11,000 cars were in service, only 126 cars of all-steel or steel underframe construction have been destroyed in service. During this same period, about 20,000 cars of wooden construction have been taken out of service on account of damage.

The cars of the type shown by figure 36 have been built with trucks of 50-tons, and designs have been prepared and arrangements made for the construction of trucks for use with this car of 70-tons capacity; the trucks to be provided with rolled steel wheels. This illustrates the tendency to reduce the weight of the car and increase the weight of lading per vehicle. With the 50-ton truck, the weight of the lading is 71·75 per cent of the gross weight of car and lading, while with the 70-ton truck the weight of the lading will be 75·5 per cent of the gross weight. It is the American practice to permit a lading of 10 per cent in excess of the marked capacity of the car.

Rolled steel wheels have been used in large numbers during the last few years; the Pennsylvania Railroad system having at the time of this report 125,000 in service.

The number of passenger carrying cars of steel construction in service and building is increasing rapidly; such cars being constructed and used both by the railroad companies and the Pullman Company (which company operates the majority of the sleeping cars in America).

The conclusions of my report are as follows :

1° The present practice in America in the construction and designing of locomotives, freight cars and passenger cars is to use steel either of rolled or pressed shapes, or steel castings for many parts, extending to practically the complete car;

2° The progress made in design and manufacture in steel of the various details of locomotives and cars, such as tubes, wheels, bolsters, truck frames, and similar parts, indicates that further substitution of this material for wood, wrought and cast iron may be expected;

3° While steels of special alloy or composition have been utilized in the building of railway rolling equipment, neither the quantity

(1) Vide *Bulletin of the Railway Congress*, number of February, 1910, p. 559.

used nor the length of time in service is sufficient to warrant any expression as to the possible economy to be obtained by their use;

4° The use of steel construction of railway rolling equipment has generally given advantageous results, both from a service and economic standpoint, as compared with the results obtained with the material for which it was substituted.

The President. (In French.) — As Mr. Ettenger, reporter, is not present, I call upon Mr. Hönigsberg to give a summary of his report.

Mr. Hönigsberg, *reporter.* (In German.) — In my report I include, besides the steels expressly designated special steels, also those for which a minimum ultimate tensile strength of 60 kilograms per square millimetre (85,340 lb. per square inch) is specified; this is in agreement with the instructions given to us by the Executive Committee of the Permanent Commission after the reporters had, at the suggestion of Mr. Le Blant, exchanged communications on the subject. As regards steel for springs, which generally has greater strength, we also considered, quite independently of any lower limit of strength, the steels which are expected for some reason or other (addition of other elements, treatment or method of manufacture) to have properties superior to those of the steels generally used for the same purpose.

The answers received concern axles, tires, springs and a certain number of miscellaneous parts. As regards plate and draft and buffing gear, I have no information. As a rule no particulars are given as regards the composition of the steels. As regards electric steels, several administrations state that trials are going to be made; I have no other information about this point.

Crank axles. — Special steel is nearly always used in the case of crank axles, particularly in the case of new designs and renewals; especially steel containing 1 to 7 per cent of nickel, generally 5 per cent, and having an ultimate tensile strength of at least 60 kilograms per square millimetre (85,340 lb. per square inch), an elongation of at least 18 per cent and a contraction of area of at least 45 per cent. The results are good; however, the proper shape of the axle seems to play a considerable part, that is to say a shape which approaches to a uniform-resistance shape, such as is obtained in the modern types with oblique arms and without middle bearing.

Straight axles. — Special steels are used by a certain number of administrations for the straight axles of locomotives, sometimes also for those of tenders, in most cases as an experiment: nickel steel having an ultimate tensile strength of at least 50 to 60 kilograms per square millimetre (71,114 to 85,340 lb. per square inch), an elongation of at least 17 to 18 per cent, and a contraction of area of at least 35 to 45 per cent; crucible steel having an ultimate tensile strength of at least 60 kilograms per square millimetre (85,340 lb. per square inch), an elongation of at least of 20 per cent, and a contraction of area of at least 35 per cent; and in one case, special steel having an ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch), without further specification. The results obtained do not agree; however, in the case of recent locomotives running at

higher speeds or developing greater tractive efforts, special steels are generally used.

Tires. — Tires made of steel having an ultimate tensile strength exceeding 60 kilograms per square millimetre (85,340 lb. per square inch) are employed by the railways considered in my report on nearly all their fast and powerful locomotives and on their tenders, in many cases also on all locomotives and tenders, in some cases also on passenger carriages. As a rule crucible steel and special Martin steel are used, having an ultimate tensile strength of at least 60 to 70 kilograms per square millimetre (85,340 to 99,560 lb. per square inch), an elongation of at least 10 to 15 per cent, and a contraction of area, when this is specified, of at least 25 per cent. Tires made of steel having ultimate tensile strength of at least 80 to 82 kilograms per square millimetre (113,780 to 116,630 lb. per square inch) (special crucible steel, chrome steel), specified in some cases to have an elongation of at least 10 per cent and a contraction of area of at least 25 per cent, and having in other cases no further specification, have only been in use recently, in most cases as an experiment.

Under the conditions which exist in the countries I am dealing with, as regards fixing (shrinkage), wheel-loads (7 to 8 tons as a maximum) and drop tests (generally blows of 3,000 kilogrammetres (21,700 foot-pounds) until the reduction of diameter is from 9 to 12 per cent), there seems no risk of fracture, even in the case of very hard steels.

I have but little information about the wear and the mileage per millimetre of reduction of thickness of the tire by friction and by truing up. The comparison of the different figures is also made difficult by the great influence of the profile and the working conditions of the line. Comparative trials have as a rule only been started lately; as regards tires with an ultimate tensile strength of over 80 kilograms per square millimetre (113,780 lb. per square inch), as yet no results have been obtained in the majority of cases.

The special steels hitherto used in ordinary practice are generally considered to be of equal value. In one case (Aussig-Teplitz), crucible steel and special Martin steel, having an ultimate tensile strength of at least 70 kilograms per square millimetre (99,560 lb. per square inch), showed a 40 per cent superiority over basic Martin steel having an ultimate tensile strength of at least 60 kilograms per square millimetre (85,340 lb. per square inch). In another case (Alsace-Lorraine), crucible steel having an ultimate tensile strength of at least 70 kilograms per square millimeter (99,560 lb. per square inch) showed a 50 per cent superiority over basic Martin steel having an ultimate tensile strength of 50 kilograms per square millimetre (71,114 lb. per square inch). Nevertheless, in this last case, hard steel is only considered necessary in the case of locomotive wheels having a diameter exceeding 1·50 metres (4 ft. 11 in.), and in the case of small locomotive wheels which are heavily loaded.

Springs. — In the case of locomotive springs, special steels are often used in cases where other springs had proved unsatisfactory, or where the load had been increased and it was desired to avoid making the springs larger. Such steels are used, in the case of passenger car-

riages, especially and to a rather considerable extent in the case of bogie carriages with four axles, sometimes also in that of goods wagons of large capacity and finally, in individual cases, for the springs of the draft and buffing gear.

Many administrations specify an ultimate tensile strength of at least 75 kilograms per square millimetre (106,670 lb. per square inch) in the unhardened condition, an elongation of at least 12 to 14 per cent, and at least 105 for the ultimate tensile strength plus twice the elongation; in the bending tests, the load is increased by 10 or 20 per cent; or else the the ultimate tensile strength is to be at least 85 kilograms per square millimetre (120,890 lb. per square inch), the elongation at least 12 per cent, and the ultimate tensile strength plus twice the elongation at least 100 to 115, with 30 p. c. more load in the bending tests, as compared with the ordinary spring steel.

The results obtained in practice are uniformly stated to be : greater elasticity, smoother and steadier running of the stock, few fractures, readjustment less frequently necessary.

Miscellaneous parts. — Steel having an ultimate tensile strength of at least 60 kilograms per square millimetre (85,340 lb. per square inch), and especially in the case of recent locomotives for high speeds and great power, crucible steel is used for the piston and valve rods, crank pins and coupling pins, etc. In some few cases, generally as an experiment, nickel steel of the same quality as that used for axles, is also of late used for connecting rods, crank pins and pinion wheels. No particular information about this subject is yet available. It may be noted that favourable results have been obtained on the Prussian State Railway with cranks made of " compound " steel or of special cemented steel.

As regards all these parts, it is very difficult to draw any definite conclusions, except perhaps in the case of springs.

On the one hand, the influence of the design of the rolling stock and the working conditions, particularly as regards plan and profile of the line, is so great that it often exceeds the influence of the difference of the materials. Hence in order to obtain figures, which we can compare, about the value of the different materials in actual practice, we cannot extract them from the general statistics, and we may draw attention to the initiative of the Prussian State Railway, which since its reorganization has done away with the greater part of its general statistics, and utilize for practical trials the staff and the credits thus made available.

From this point of view, metropolitan railways form a class apart, as they have rolling stock of uniform design and uniform conditions of working; some of them could evidently be used as experimental lines for trying different kinds of steel.

A second difficulty is this : when a metal has shown its properties in actual practice, how can it be sufficiently decided by tests so as to know, in subsequent cases, that one has metal of the same quality? If the metal of an axle has the tendency to break in consequence of the shocks it receives in practice, in consequence of minor injuries, that tendency is revealed neither by the tensile test nor by the ordinary drop test. These tests still less enable us to foresse whether a tire will wear quickly or slowly when in use.

It would hence be very useful, when making the practical trials, to make also as many tests as possible in order to ascertain what tests best correspond to the results obtained in practice, and what conditions should be specified for these tests.

In many cases, particularly in that of tires, owing to their quick wear on a bad track, the use of a special steel and of steels of superior quality depends on whether the superiority of the steel in question can be determined by trials in practice, and whether that steel can, when subsequently supplied, be recognized as of equal quality by tests, even if those tests are not obligatory.

At its last meetings, the International Association for testing materials already enunciated the bases of supplementary tests, intended to show the principal properties of the metal when in actual use; on the other hand, the steel-works themselves which make steel of superior quality try to show by more severe tests, that their metal is really of greater value; in this case the interests of the consumer and the interests of the producer go hand in hand.

In the case of railways, the use of steels which actually increase the durability of parts may form a source of economy of material, of the cost of machinery and of the time the stock must be idle when under repair, which may suffice to stop further increases in the coefficient of working.

The following are my conclusions :

1° Springs of special steel of high resistance make vehicles run more smoothly and fewer are broken; they require adjustment less frequently, particularly in the cases in which other materials have proved unsatisfactory, or when it has been desired to avoid using reinforced springs for the increased loads;

2° In the case of crank axles, special steel is nearly universally used, preferably 5 per cent nickel steel which has given good results, but only when the axles have had a suitable shape;

3° Tires of special steel of high resistance are generally used for fast and for powerful locomotives, and for the tenders they haul; often also for other locomotives and in some cases also for passenger stock. The risk of fracture of these tires of high-resistance steel is not great if the tires are tested by impact tests and if they are fixed by means of a retaining ring. As regards wear, particularly on mountain lines and on curves, it has not yet been possible to ascertain in a general and satisfactory manner whether these kinds of steel are suitable;

4° Steels of high resistance are much used for the straight axles of modern locomotives, as well as for the tenders and sometimes also for the carriages; sufficient and uniform data on the subject of these steels are not yet available;

5° The use of special steel of high resistance for the different parts of the rolling stock is becoming more and more necessary, as the forces acting on them are continually increasing. It is advantageous from the economic point of view in the case of parts that need renewal frequently. But its use will only develop if it is possible to prove definitely and quickly that such steel is superior in practice, and, as far as possible, to show this by preliminary tests;

6° In order to determine the comparative value of different kinds of steel, as regards their behaviour in practice, the general rolling stock statistics do not suffice, except on lines which have uniform rolling stock and uniform working conditions, such as metropolitan railways. It is hence necessary to make special trials under exactly similar working conditions;

7° In order to define sufficiently the special steels recognized as superior, it is advisable to make, besides the specification tests, special tests in order to show, as far as possible and directly, the essential qualities of these steels (safety against fracture resulting from blows, unfavourable shape; resistance to wear, etc.).

The President. (In French.) — As Mr. Worsdell, reporter, is not present, I will call upon Mr. Le Blant to give a summary of his report.

Mr. Le Blant, *reporter.* (In French.) — In the first place I must cordially thank the eminent engineers of the different administrations for their interesting answers to the list of questions which was sent to them by the intermediary of the general secretary of the Permanent Commission.

The information given in my report dates back more than a year, and hence it is clear that as the subject is still in its infancy, the particulars given have already become incomplete. A correct idea of the value of a material used in constructing rolling stock can only be arrived at after a certain time has elapsed. If an article has to be taken out of use on account of wear or of fracture, after it has been used for a small mileage only, one knows at once how matters stand, if the question of dimensions does not come in. If, on the other hand, the article can be used for a considerable mileage before it becomes useless, the trial period is the longer, the better the material used.

On the other hand, it would not be logical to decide to reject a given material owing to a single fracture due to some accidental circumstance, to some unknown cause which would perhaps never recur if a large number of trials were made. It is hence advisable to wait, before coming to a decision, until the whole lot which is being tried has had to be repaired or renewed.

These considerations will explain why in my report I give so few results obtained in practice. Among the railways which have supplied me with information, only few were able to give me figures as to mileages. I therefore propose only to speak to you about the latter.

The principal parts made of special steel are crank axles and tires. On the French Eastern Railway, we are using axles made of chrome-nickel steel and of nickel steel, quenched and annealed. The chrome-nickel axles have on the average an ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch), with an elongation of 21 per cent. The drop test consists of a blow of 1,500 kilogrammetres (10,850 foot-pounds) given to a bar having a cross-section of 30×30 millimetres ($1\ ^3/_{16} \times 1\ ^3/_{16}$ inches), on supports 160 millimetres ($6\ ^5/_{16}$ inches) apart; no crack or fracture must appear.

The nickel axles have on the average ulimate tensile strength of 67·7 kilograms per square millimetre (96,300 lb. per square inch), with an elongation of 18·2 per cent. The drop test on test bars is carried out in just the same way.

All the test pieces are cut lengthways.

The chrome-nickel steels contain on a average 1·5 per cent of nickel and 0·2 per cent of chromium.

As working results, we may mention the following mileages, up to 31 December 1908 :

473,000 kilometres (293,900 miles) for

the 4-4-0 high-speed locomotives, with extremes of 349,000 and 540,000 kilometres (216,800 and 335,500 miles);

530,000 kilometres (329,300 miles) for other types of locomotives, with extremes of 489,000 and 574,000 kilometres (303,850 and 356,700 miles).

None of these axles showed any cracks. It is true that none of the ordinary-steel axles used on these two series of locomotives have as yet had to be taken out.

The French Northern Railway uses chrome-nickel axles which are hardened and tempered, having an ultimate tensile strength of about 67 kilograms per square millimetre (95,300 lb. per square inch), an elongation of 19·5 per cent and an elastic limit of 49 kilograms per square millimetre (69,700 lb. per square inch). Of the crank axles in use, 8·5 per cent are made of this steel.

The increase in mileage recorded by the company has varied, with the different locomotives, between 6 and 117 per cent.

The French Northern Railway seems disposed to extend the use of these chrome-nickel axles.

The Paris-Lyons-Mediterranean Railway uses axles made of chrome-nickel steel, and of nickel steel. As regards the chrome-nickel axles, the trials have not yet gone very far. Several premature fracture have, however, been recorded: one fracture at 150,000 kilometres as against 332,000 kilometres (93,200 miles as against 206,300 miles), ordinary steel, but only half of these special-steel axles have been withdrawn from use since 1897.

One fracture at 48,000 kilometres as against 119,000 kilometres (29,800 miles as against 73,900 miles), ordinary steel; but one axle out of two is still in use.

One fracture at 176,000 kilometres as against 322,000 kilometres (109,400 miles as against 200,000 miles), ordinary steel; but four axles out of five are still in use. Other mileages are more satisfactory.

In the case of nickel-steel axles, the mileage was 225,000 kilometres as against 275,000 kilometres (139,800 miles as against 170,900 miles) with axles of ordinary steel; 28 per cent of the locomotives were equipped with axles of special steel.

It seems that the following conclusions can be drawn from the particulars mentioned:

A fairly considerable number of railways is making trials of cranked axles for locomotives, made of special steel of high resistance. The experimental period is not yet concluded, and there is only one company, the Northern Railway, in France, which appears to have decided to extend this application.

The administration of the Swiss Federal Railway kindly informed me, in October 1909, that as a result of observations made in practice, it was going to give up the use of ordinary crucible steel and adopt 5 per cent nickel steel for making certain locomotive crank axles. It only uses the latter metal in the case of the locomotives of certain series.

Thus we actually only find two railway systems, the French Northern and the Swiss Federal, which seem to have decided regularly to use special steel for making their crank axles.

I pass to tires. The Orleans Railway in 1892 put in use twenty tires of very hard steel, having an ultimate tensile strength of 90 kilograms per square millimetre (128,000 lb. per square inch) and an elongation of 9 per cent. In consequence of fractures while in use, these

tires were taken out; they had run about 40,000 kilometres (24,850 miles) and they had become worn as much, if not more, than tires of ordinary steel.

On the French Eastern Railway, we have tried tires of three kinds of extra-hard steel : ordinary carbon steel, but hardened and tempered; chrome steel and nickel steel. These tires have as a rule given better mileages than the ordinary tires. Particulars of these mileages are given in my report.

It is to be noted that a great mileage before wear appears is not the only quality the tire must have.

It, in fact, frequently happens that small pieces, like straws, become torn out more or less completely from the rolling surface, and make it necessary to return the surface sooner, or to take out a tire having a mean thickness still considerably exceeding the regulation thickness. We are not clear as to the origin of these defects.

Be the reason what it may, if we classify the four kinds of steel used on the French Eastern Railway, we find that the nickel and chrome steels are better than the carbon steels.

The St. Gothard Railway uses tires made of Martin steel having an ultimate tensile strength of 75 kilograms per square millimetre (106,670 lb. per square inch), with an elongation of 16 to 18 per cent. These tires are reheated and cooled slowly after they have been rolled.

They are fitted on wheels with axle-loads of 15 to 16 tons (14·8 to 15·7 English tons) in the case of drivers and of 10 to 14·5 tons (9·84 to 14·3 English tons) in that of carrying axles and they are braked 60 to 70 per cent of the adhesive weight.

The results obtained in practice as compared with those given by tires of ordinary steel are as follows, the wear being calculated per 1,000 kilometres run. Special steel tires showed a wear of 0·10 to 0·11 millimetre (0·0063 to 0·0070 inch per 1,000 miles), while ordinary tires showed a wear of 0·15 to 0·17 millimetres (0·0095 to 0·0108 inch per 1,000 miles). Thus this is considerably in favour of special steel.

I next have to speak of parts other than tires and axles. In this case, I have received no information as to results obtained in practice.

The parts which are being tried are straight axles made of chrome-nickel steel, on the French Northern and the French Eastern, cranks, crank pins, piston rods and spring hangers, on railways in various countries.

Since the printing of my report, we have made, on the French Eastern Railway, several hundreds of coupling screws of extra-hard steel containing 2 per cent of nickel. This is a steel having an ultimate tensile strength of over 50 kilograms per square millimetre (71,114 lb. per square inch) and an elongation of over 18 per cent, with an elastic limit of 35 kilograms per square millimetre (49,780 lb. per square inch), while the ordinary steel of the French railway specifications only had an ultimate tensile strength of 36 kilograms per square millimetre (51,200 lb. per square inch) in the case of steel A and of 41 kilograms per square millimetre (58,310 lb. per square inch) in that of steel B, the elongations being 30 and 28 per cent respectively. Thus the special steel has much greater strength, nearly twice as much, but a smaller elongation.

The use of nickel steel will accordingly enable us to increase the test loads of our couplings, from 50 to 65 tons. We thus will have 30 per cent more strength, the movable part of the coupling remaining of the same weight.

In order to continue the investigation of extra-hard tires, the working results of which are given in the report, we are at present using nickel-steel and chrome-nickel-steel tires on certain selected locomotives and tenders ; but several years will probably still have to elapse before we can decide as to the advantages to be obtained from the use of these steels.

To sum up, very few results have been obtained in practice, but an appreciable number of railway systems are interested in the question and are carrying out trials on a smaller or larger scale. The question accordingly is, as I have already stated, still in its infancy.

The President. (In French.) — Mr. Le Blant's report can now be discussed.

Mr. Kabodi. (In German.) — The great importance of the question of crank axles leads me to refer to a remark made by the reporter. He states that the results obtained with crank axles made of nickel steel have generally been favourable. I do not agree with this verdict, for on the Hungarian State Railway we have, as yet, not had very satisfactory results. We have more especially a type of heavy express locomotives where the nickel-steel crank axles broke so frequently that it was necessary to replace them after a very short time. Detailed tests and investigations which we made in order to ascertain the causes of these fractures, and the answers which we received to circular letters which we addressed to European railways on this question, led us to recognize that the question of nickel-steel crank axles is still in the elementary stage. Tensile tests have shown that the metal is homogeneous in some places but not in others. It was found that where the crank arm begins the metal had quite a different structure. Tests subsequently made showed that the reason for this was that at that point the forging was very incomplete. It also seemed necessary to modify the shape of the axles, so that the working and the machining of these crank axles were the same everywhere. It was also tried to make these crank axles in three pieces. If I am correctly informed, there are English railways which have up to eight pieces in such built-up crank axles.

I therefore would ask the reporter if unfavourable results, from this point of view, have also been recorded elsewhere.

Mr. Hönigsberg. (In German.) — According to the information supplied to me for drawing up my report, there were, in the countries to which my inquiries apply, neither cracks nor fractures of nickel-steel crank axles, at the end of 1908. However, it seems that the influence of the shape, the importance of which I emphasize in my report, is much less marked in the case of nickel steel than in that of ordinary steel. As regards axles made in three pieces, I know that the Austrian State Railway uses them. I think that the facts mentioned by the last speaker are the best argument which can be urged showing the deficiency of existing tests. I am not specially considering tensile tests. As long as we are

limited to these — and that continues to be the opinion of many engineers, because the other tests are not perfected to the same extent — these tensile tests will always be useful. But we have no guarantee whatever that an article is of the same quality at all points It would be advisable to cut these test pieces out of the inside of the mass. A large number of crank axles have been drilled in order to see whether there is piping. It would certainly be possible, without injuring the strength, to increase the diameter of the hole sufficiently to be able to use core drills. Calculation confirms that this would not be of much importance. It would then be easy to take the best pieces from inside, that is to say, to use the core. I know that not only marine-engine builders, but also the great electro-technical works proceed in this way. Tensile tests would give a better guarantee, if the test pieces were cut out of the core drilled out of the crank. Then there is the impact test made on notched bars, so as to exclude any metal which might have a tendency to crack in the crank arms.

Mr. Rohr, Alsace-Lorraine State Railway. (In German.) — On the Alsace-Lorraine State Railway, we have for many years had a large number of nickel-steel axles in use, and up till now there has been no single case of fracture.

Mr. Kabodi. (In German.) — Made in one piece?

Mr. Rohr. (In German.) — Yes.

Mr. Greppi, Italian State Railway. (In French.) — Gentlemen, I wish to add some information to that given in Mr. Le Blant's report, on the subject of nickel-steel crank axles. We have at present a large number of nickel-steel crank axles in use; we have 779 locomotives with such axles. Now with this large number of locomotives, we have as yet had no cracked axle.

Formerly we used a nickel-steel containing about 7 per cent of nickel.

All the axles made of this steel — there were eighteen of them — cracked; this happened between 1902 and 1903. Since 1903, we have adopted a nickel-steel containing 5 per cent of nickel and, with this alloy, we have not had a single cracked axle. The mileage made — I am talking of axles, the oldest of which date back to 1904 and 1905 — represent as a maximum 420,000 kilometres (261,000 miles). We have, however, observed one disadvantage : sometimes the axle-journals have become worn irregularly, the metal being abraded. We have noticed this peculiarity more frequently in the case of nickel-steel axles that in that of axles made of ordinary steel.

Mr. Antochine, *principal secretary.* (In German.) — Different figures are given for the nickel content; they vary from 3 to 10 per cent. It would be interesting to know how this content is determined. Is it the finished axle which is analysed?

The President. (In German.) — I think that each administration has its own specification, arrived at empirically. In Austria and in Hungary, 3 per cent is not readily exceeded. We have tried a smaller nickel content and our experience has led us to the figure of 3 per cent. Our colleague from the Italian State Railway tells us of a nickel content of 5 to 6 per cent; that information has interested me very much.

Taking it altogether, I think that the different administrations specify the nickel content and do not leave it to the steel works to decide this point.

Mr. Le Blant, *reporter.* (In French.) — In any case, in France, we specify guarantees under which the axles are accepted.

The President. (In French.) — Do you not also specify a maximum content?

Mr. Le Blant. (In French.) — I do not think it is necessary to specify a maximum, for as nickel is expensive, the content is limited by the high price.

The President. (In French.) — No doubt, but it might happen that carelessness in the manufacture or a mistake might result in an excessive nickel content.

Mr. Le Blant. (In French.) — Besides the specification relating to the chemical analysis, we also specify physical tests which protect us against any errors at the works.

The President. (In French.) — The tests are then very severe in the case of this material?

Mr. Le Blant. (In French.) — Yes, but up till now at all events the French works have had no difficulty in supplying us. Actually, as regards crank axles, the specifications are fixed by agreement with the works. We have in fact in France no uniform technical specifications for the supply of crank axles.

The President. (In French.) — We have specified very severe conditions as regards mileage guarantees.

Mr. Le Blant. (In French.) — There is evidently also the mileage guarantee, but this varies with the different series of locomotives.

The President. (In French.) — And according to the axle-load.

Mr. Keller, Swiss Federal Railway. (In German.) — The Swiss Federal Railway has about 400 locomotives with crank axles in use. Formerly crank axles made of crucible steel were used, and gave bad results; numerous cracks were formed in the crank arms. It was then decided only to use crank axles made of steel containing 5 per cent of nickel, and with these we have obtained very good results. Some of these axles have run up to 600,000 or 700,000 kilometres (373,000 or 435,000 miles), without any damage; they are now still in use. We have arrived at the conclusion that a good nickel steel made by a trustworthy manufacturer gives the best results. The nickel content is not checked chemically. It is left to the works to see that it contains 5 per cent.

Mr. Greppi. (In French.) — I will answer the question asked. At first we used axles made of steel containing about 7 per cent of nickel. At present we specify exactly 5 per cent, that is to say, we require the nickel content to be nearly as possible 5 per cent.

Mr. Salomon, French Eastern Railway. (In French.) — Would Messrs. Greppi and Rohr kindly give further particulars about the information they have just supplied?

Mr. Greppi has given the mileages of the nickel-steel axles, but we should know the mileages of axles made of ordinary steel, of axles made of carbon steel and used on locomotives of the same series and doing similar work. That is, in fact, the point.

On the other hand, Mr. Rohr has told us that on the Alsace-Lorraine State Railway many nickel-steel crank axles have been in use a certain number of years. It would be very interesting to know the mileages and have particulars of the locomotives with which these axles are used; at the very least, we should know the adhesive load on the driving axle. This would show us what the advantage of special-steel axles was.

The President. — Perhaps our colleagues from America and England can give us some information about nickel-steel crank axles.

Mr. Fowler, Midland Railway, England. — The Midland Railway, as well as the majority of English Railways, do not use nickel-steel axles. We make use of high carbon steel, and find that it does not give any special inconvenience owing to the wearing of the big end, but the only difficulty is that resulting from fractures.

The results obtained with this steel are so satisfactory that the adoption of nickel steel does not appear necessary.

Some weeks ago we took out an axle which had run 1,000,000 kilometres (621,400 miles).

The President. — Then the reason why you do not use nickel steel is simply a question of the price?

Mr. Fowler. — The reason is that we are satisfied with the ordinary carbon steel.

Mr. Kabodi. (In German.) — I would like to ask whether these crank axles are made in one piece or are built up. That is the most important point.

Mr. Fowler. — The Midland Company only use crank axles of ordinary carbon steel made in one piece. Some other English Companies sometimes use built up axles, and in such cases they use chrome-nickel steel. Mr. Cooke of the London & North Western Railway will confirm what I have said.

Mr. Cooke, London & North Western Railway. — The London & North Western Railway uses crank axles made of chrome steel.

Mr. Courtin, Baden State Railway. (In German.) — If I correctly understand Mr. Salomon, he wishes to know, and have the figures, what the life of a nickel-steel axle is compared with that of a crucible-steel axle. I may state that the results obtained from this point of view are given in Mr. Hönigsberg's report. With the old express locomotives, total number of crucible-steel axles forty, we have had altogether five fractures. The mileage of an axle before it broke averaged 433,350 kilometres (269,280 miles). With the 4-6-0 express locomotives, with cylinders acting on two different axles, total number of crucible-steel axles eighty-six, we have had six fractures, after an average mileage of 468,200 kilometres (290,930 miles). In addition we have *Atlantic* express locomotives, of more recent type, with four cylinders acting on the same axle. These locomotives had nickel-steel axles from the start. On 1 January 1909, the average mileage was 463,000 kilometres (287,700 miles); now we may take it that it has reached 600,000 kilometres (373,000 miles). Up till now, not one of these axles has been broken. On the other hand, we have been informed that one axle of a *Pacific* locomotive has been broken. This was not a case of the ordinary break-

ing across of an axle, but of longitudinal cracks. There must have been a defect in the manufacture; this matter has not yet been cleared up. This locomotive has run a distance of about 18,000 or 19,000 kilometres (11,200 or 11,800 miles). I can assert, on the basis of our experience, that the nickel-steel axles have proved satisfactory from every point of view.

The President. (In French.) — Then you will find the information you desire in Mr. Hönigsberg's report. Does that satisfy you, Mr. Salomon ?

Mr. Salomon. (In French.) — Yes, sir.

The President. (In French.) — Mr. Courtin has just stated that crank axles have given mileages up to about 600,000 kilometres (373,000 miles), and that there has been no case of fracture. These results are noteworthy.

Mr. Lavialle d'Anglards, Portuguese Railway Company. (In French.) — The results just given by Mr. Greppi, relating to a very large number of nickel-steel crank axles, are very interesting. I will venture to ask him if the Italian State Railway specified, to the manufacturers, the way in which the metal was to be treated, and if so, what tensile tests and impact tests were specified.

We have recently had occasion to order a number of nickel-steel crank axles and left it to the manufacturers to state what guarantees they were prepared to give; and we naturally selected the steel-works which asked the lowest price while guaranteeing satisfactory conditions. Now the works found it impossible to satisfy the conditions regarding non-brittleness which they had guaranteed, even when they made the axles a second time.

Hence, I should like to know whether the Italian State Railway specified conditions as to the treatment of the metal, that is to say, conditions as regards hardening and tempering, and as regards the mechanical properties, the tensile strength and particularly the resistance to blows.

Mr. Greppi. (In French.) — The following is the exact technical specification which our locomotive crank axles must satisfy :

The crank axles shall be made of steel of first quality, containing 5 per cent of nickel.

They shall be made from ingots weighing not less than 12 tons, the upper third of which is to be rejected.

The origin of the materials used, the manner of forging and of annealing shall be approved in advance by the administration, to whom the supplier shall send a detailed report about his process of manufacture.

All the axles shall have at each end extra pieces at least 500 millimetres (1 ft. 7 $^{11}/_{16}$ in.) long, having a diameter not less than that of the axle. These pieces shall be used for making the test pieces for the tensile, the bending and the impact tests. Two tensile and bending tests shall be made with each axle, that is one for each end; there shall be one impact test to each axle.

The tensile tests must show :

An ultimate tensile strength of between 55 and 70 kilograms per square millimetre (between 78,225 and 99,560 lb. per sq. inch).

An elongation of not less than 18 per cent measured on a length of 200 millimetres (8 inches) between datum marks;

An elastic limit of not less than 38 kilograms per square millimetre (58,045 lb. per square inch).

The test pieces for the bending test shall

have a square cross-section of 25 × 25 millimetres (1 × 1 inch), and shall first of all be heated cherry red and then suddenly cooled in water having a temperature of 25° C. (77° Fahr.). They shall then be bent round a bar having a diameter of 60 millimetres (2 3/8 inches), through an angle of 180°, that is to say until the two ends of the test pieces are parallel.

The impact tests shall be made on test pieces having a circular cross-section 40 millimetres (1 9/16 inches) in diameter, and having a length of 400 millimetres (1 ft. 3 3/4 in.); the test piece shall be supported on a rigid mass and notched in the middle and on one side only by a chisel, on to which a weight of 25 kilograms (55 lb.) is dropped from the height of 1 metre (3 ft. 3 3/8 in.). The bar shall then be supported notch downwards on two rounded supports 300 millimetres (11 13/16 inches) apart. In this position it must then stand, without any signs of injury, two blows given by the said tup weighing 25 kilograms (55 lb.) and falling from a height of 1 metre (3 ft. 3 3/8 in.)

I will now answer a word to Mr. Salomon who asks whether we have any results with nickel-steel axles and axles made of ordinary steel. We are not able to give any comparative figures. Our oldest locomotives with crank axles date back to 1900. Those crank axles were made, as I have already stated, of steel containing 7 per cent of nickel. They were taken out of use at the end of two or three years because cracks formed.

We then fixed 5 per cent as the maximum nickel content, and all the new nickel-steel axles used for locomotives since 1903 are still at present in use, except one of these axles, which was, quite exceptionally, taken out because the journals were worn. No crack has been observed.

Mr. Keller. (In German.) — The Swiss Federal Railway is able to give some information about the mileage of crank axles. I wish to emphasize that if one wishes to make a reliable comparison, it must apply to one and the same given series of locomotives doing similar work. The shape and the fatigue of crank axles are of very great importance. This is the information I can give you about the mileage of the axles on the Swiss Federal Railway. We have a series of twenty-five locomotives which have been in use since 1897. They have crank axles made of crucible steel; none of them has yet shown any cracks, although they have run over 600,000 kilometres (373,000 miles). No doubt this result is due to the rather limited fatigue of these locomotives; they are A 2/4 compounds with four cylinders. Some of the other more powerful locomotives with crank axles made of crucible steel after running less than 100,000 kilometres (62,100 miles) already showed, not fractures, but cracks at the cranks. It was the shape which came into question. Nickel-steel crank axles made of the same shape, and used with the same series of locomotives, did not give these disadvantages, as out of all the nickel-steel axles, which have run up to 700,000 kilometres (435,000 miles), only two have shown slight cracks. We broke up one in order to use it for making strength tests; the other could be repaired by re-turning in the lathe, and it is still in use. We have at present 206 nickel-steel crank axles and are sure of getting good results with them. But we cannot yet make any definite comparison between them and crucible-steel crank axles.

Mr. Herdner, Midi Railway, France. (In French.) — We have tried a certain number of crank axles made of chrome-nickel steel. Unfortunately these axles have as a rule not satisfied expectations. Most of them showed cracks after a mileage hardly equal and often less than the mileage of other axles made of ordinary steel, before the appearance of the first crack. Thus one series of ten axles, used with locomotives of the *Atlantic* type showed cracks after runs of from 70,000 to 300,000 kilometres (43,500 to 186,500 miles). Six other axles, supplied subsequently, also made of chrome-nickel steel, have it is true as yet no cracks, but their mileage is as yet small.

We have also other crank axles in use, made of ordinary carbon steel, of the quality known as gun steel. These axles have been subjected to a heat treatment, and were hardened and tempered; used with express locomotives with bogie and two coupled axles, they gave mileages of 570,000 to 600,000 kilometres (354,000 to 373,000 miles) before the first cracks appeared. Those are the best results we have as yet obtained; and they were obtained with ordinary steel and not with special steel.

It has seemed to us, but as yet this is only an impression, that the question of heat treatment, of hardening and tempering, may be of greater importance to these steels than that of chemical composition; but that is, I repeat it, only an impression. In order to make a conclusive comparison, the two types of axles should be used with locomotives of exactly similar type, for it seems to us that the type of the locomotive also has a considerable influence on the life of the axles.

Mr. Hönigsberg. (In German.) — I should like to ask Mr. Herdner for some information about the latest results obtained with the Frémont process which he has introduced on the Midi Railway.

Mr. Herdner. (In French.) — In answer to Mr. Hönigsberg's question, I will tell him that we only use crank axles of the Worsdell type. In consequence of cracks which formed, we applied to a certain number of these axles the Frémont process, which consists in making a hollow in the web, in the space between the axle and the crank. I am not yet able to give any definite figures about the value of this alteration, as it is still too recent. I am, however, convinced that it will enable us to make the axles last longer than if we let them die their natural death after the appearance of the first crack. I have no figures here, but some have been published in the *Revue générale des chemins de fer*. We have observed that the axles continue to act well since. Only one of them, some time after it had been altered, showed a new crack, and this we attribute to a local defect.

I must add that as a rule we do not apply the Frémont process until the first crack has appeared, and when the process makes it possible to remove it. We have applied this process, as an experiment, to one lot of four new axles. These axles are made of chrome-nickel steel. As yet results are satisfactory.

Mr. Courtin. (In German.) — The Frémont process was applied to the crank axle of a locomotive on the Baden State Railway about a year ago, and that locomotive has run about 60,000 kilometres (37,300 miles) since without any trouble.

Mr. Salomon. (In French.) — That is very little.

Mr. Herdner. (In French.) — We have greater mileages, but I cannot quite remember them and I do not wish to give any inaccurate figures.

The President. (In German.) — May I now close this discussion, and ask you to hear Mr. Steinbiss?

Mr. Steinbiss, *vice-president.* (In German.) — The Prussian State Railway and other German railways have for some time been using, as an experiment, " electric " steel for making tires and axles; this steel is made by remelting Siemens-Martin steel in an electric furnace. It was also proposed to use electric steel (ultimate tensile strength, 60 kilograms per square millimetre [85,340 lb. per square inch]), for making stronger coupling screws and drawhooks. Electric steel is characterized by the homogeneity and the purity of the metal. The numerous trials made have given good results and promise good results in future.

Mr. Greppi. (In French.) — Can we not obtain any information from the administrations who have now for some time been using, rather extensively, built-up crank axles on the English, Worsdell, system?

The President. (In French.) — I think that the discussion of this point would go too far.

Messrs. Ettenger and Worsdell are unfortunately not present. Does the section desire summaries of their reports to be given? Neither Mr. Ettenger's report, nor Mr. Worsdells's report, contains any conclusions proper. I think we can therefore pass to other matters.

I propose, gentlemen, as regards littera *A*, that we should adopt Messr. Crawford and Szlabey's conclusions, and as regards littera *B*, those of Messrs. Hönigsberg and Le Blant's.

Mr. Antochine. (In German.) — Would it not be well to put into the conclusions a definition of the term " special steel of high resistance "?

The President. (In German.) — One can in fact understand this term in different ways. Some apply it already to steel having an ultimate tensile strength of 45 kilograms per square millimetre (64,000 lb. per square inch), while others only begin to apply it to steel when this has an ultimate tensile strength of 60 kilograms per square millimetre (85,340 lb. per square inch). The term is thus very elastic.

Mr. Salomon. (In French.) — I think, in the present state of the question, as we are very doubtful as to chemical compositions and the heat treatment best suited to each of them, it would be better to use a general term than one which is more precise. Perhaps, if you like, one might say : steel other than carbon steel.

Mr. Hönigsberg. (In German.) — I wish to remark that this is exceedingly difficult in practice, as we have not enough information about the composition of the steels used. As regards fixing the strength limit per square millimetre at 60 kilograms (85,340 lb. per square inch), Mr. Le Blant's original proposal was to fix this at 60 kilograms (85,340 lb. per square inch) for axles and at 80 kilograms (113,780 lb. per square inch) for tires; I myself pro-

pose to reduce this limit for tires to 70 kilograms (99,560 lb. per square inch), seeing the working conditions in the countries my report had to consider.

The President. (In German.) — Gentlemen, I would remind you that there is in existence an International Association for testing materials. The members of that association are probably more competent than the members of the Railway Congress, to deal with a question of this kind.

Gentlemen, I think that we have finished the discussion of question V and I propose that we adjourn till tomorrow.

Mr. Fowler. — I should like to be allowed to add a word to the discussion on special steels.

— The section deciding not to continue the discussion, the meeting then terminated.

Meeting held on 8 July 1910 (morning).

The President. (In German.) — Gentlemen, these are the general conclusions concerning question V which we have the honour to submit to you :

" *A*. 1° Steel having an ultimate tensile strength of more than 44 kilograms per square millimetre (62,580 lb. per square inch), is not substituted for the wrought iron, generally used formerly, except for a small number of rolling stock parts, and that only by a few administrations. The forged or wrought iron is more generally replaced by mild steel or ingot iron having an ultimate tensile strength of 33 to 44 kilograms per square millimetre (46,935 to 62,580 lb. per square inch).

" 2° Steel castings are in many cases used to replace wrought iron in the case of parts which are of a complicated shape. They are very generally used as a substitute for cast iron in the case of parts subjected to larger stresses; their use in such cases is intended to increase security.

" 3° It seems, however, certain that the use of steel will become extended to all locomotive parts. It may be foreseen that steel cars will replace wooden cars, owing to their greater strength, their incombustibility and their less costly maintenance. Cars built entirely of steel make it possible to increase the tonnage while reducing the tare to the minimum compatible with great strength.

" *B*. 4° Many railway administrations use crank axles made of special steel of high resistance, and especially of nickel steel containing 5 per cent of nickel, a metal which has proved satisfactory provided the axles are of proper shape.

" 5° Special steel is used for straight axles only in certain special cases.

" 6° Several railway companies use steel having an ultimate tensile strength of at least 70 kilograms per square millimetre (99,560 lb. per square inch) for the tires of locomotives and tenders. If care is taken to specify impact tests, no fear of fracture need be entertained.

" 7° As it is very probable that the

interest in the use of these steels will grow, it is advisable to request the railway systems to undertake trials or to extend the trials already begun, so as to determine as soon as possible the advantages or disadvantages of the use of special steel of high resistance in the construction of locomotives and rolling stock. "

— These proposed conclusions were then adopted.

Meeting held on 13 July 1910 (morning).

The President. (In French.) — I think I must say a word about the proposed conclusions relating to special steel.

It seems to me that we have made a slight mistake. According to the text published on page 10 of No. 6 of the *Journal de la huitième session*, it would seem that clause 7 only applies to littera *B*. Now I do not think that this is correct.

Did the section wish to say that the growing interest in the use of these steels only exists as regards crank axles ?

Mr. Salomon. (In French.) — No, we consider this interest to be general.

The President. (In French.) — We should then add that clause 7 applies to both *A* and *B*.

Mr. Le Blant, *reporter.* (In French.) — As for me, I think that clause 7 only refers to the use of special steels which is considered under littera *B*. In fact, ordinary steel is used so to say as a regular thing. In France at least wrought iron is no longer used, or only used very rarely.

The President. (In French.) — Allow me to say one word. In clause 3, littera *A*, you say : " It seems, however, certain that the use of steel will become extended to nearly all locomotive parts. " Do you not wish that experiments should also be made from this point of view ?

Mr. Le Blant. (In French.) — Mr. Ettenger and I were only reporters as regards littera *B*. Hence, we could not propose any conclusions relating to littera *A*.

The President. (In French.) — That is self-evident, but this is a mere matter of form. At this moment we have to draft general conclusions relating to *A* and *B*.

Mr. Salomon. (In French.) — What disadvantage would it be if the suggestion offered in conclusion 7 were to apply to both kinds of steel as regards the countries or administrations which at present do not use steel exclusively? This would evidently not apply to France where we use steel almost exclusively.

The President. (In French.) — With us also, I think that this wish could be extended to both litteras.

Mr. Salomon. (In French.) — It is merely a question of the wording.

Mr. Lavialle d'Anglards. (In French.) — I would add the following phrase : " It would be desirable that these tests should

be made in a uniform manner and in accordance with the rules laid down by the International Association for testing materials. "

The President. (In French.) — I see no objection to this addition.

Mr. Le Blant. (In French.) — I also see no objection to adding that it would be desirable to agree to make these tests as specified by the Commission, which has an international character and has laid down rules for making tests. I wish to mention however, as regards special steels, there are not only the tests specified in the rules of the International Association, that is to say, tests made with test pieces, etc., but there is above all the test of actual service, and this is in fact the really important test. We are at present not certain whether the use of special steels is an advantage from the point of view of economy ; we do not know whether it will not be more expensive for us to buy these steels at a higher price, steels which perhaps will give no better results than ordinary steels. Now, the International Association is not concerned with such tests.

The President. (In French.) — I do not think that the wording means tests of that kind. The idea of our Portuguese colleague only relates to tests proper of the material, and not to practical tests or trials not within the scope of the rules of the International Association, and which can yet be specified for certain kinds of steel.

Mr. Salomon. (In French.) — Then the question is no longer of much interest.

The President. (In French.) — Can we perhaps agree about the following text :

" 7° As it is very probable that the interest in the use of these steels will grow, it is advisable to request the railway systems to undertake trials or to extend the trials already begun, so as to determine as soon as possible the advantages or disadvantages of the use of special steel of high resistance in the construction of locomotives and rolling stock. It would be desirable that the tests should be made in accordance with the rules laid down by the International Association for testing materials."

Mr. Salomon. (In French.) — It would then be a question of reception tests.

The President. (In French.) — Perhaps so.

A delegate. (In French.) — It is not a question of applying tests.

Mr. Le Blant. (In French.) — According to the French wording which I have before me, clause 7 only applies to practical trials, and not to reception tests or tests of test pieces.

Mr. Salomon. (In French.) — The word " *essais* " can in fact only include practical test trials.

The President. (In French.) — It is evidently not a question of tests of test pieces. It is one of practical trial.

Mr. Salomon. (In French.) — I then think that there is nothing to add to the original wording.

Mr. Hönigsberg, *reporter.* (In German.) — The administrations of the railways

which are distributed all over the world would have difficulty in coming to an agreement to make practical tests on a uniform plan, and it would in fact be better to lay down in the first place rules which could be recommended, with a view to obtaining comparable figures.

Mr. Le Blant. (In French.) — That is a matter for the International Association for testing materials.

The President. (In French.) — That is why it would be better not to use the words « in a uniform manner », and simply say :

" It would be desirable that the specification tests should be made in accordance with the rules of the International Association for testing materials. "

— If the section agrees, I declare this text adopted. (*Agreed.*)

DISCUSSION AT THE GENERAL MEETING

Meeting held on 14 July 1910 (afternoon).

MR. P. WEISSENBACH, PRESIDENT, IN THE CHAIR.
GENERAL SECRETARY : MR. L. WEISSENBRUCH.
FIRST ASSISTANT GENERAL SECRETARY : MR. MÜRSET.
SECOND ASSISTANT GENERAL SECRETARY : DR. A. BONZON.

Mr. Gertsner, *president of the 2nd section*, reads the

Report of the 2nd section.

(See *Journal de la huitième session*, No. 6, p. 8.)

LITTERA *A*.

" Mr. KABODI (*Hungarian State Railway*), acting for the reporter, Mr. Szlabey, who was absent, gave a summary and read the conclusions of the report in question.

" Mr. CRAWFORD then reads the conclusions of his report.

" The reports and the conclusions contained in them did not give rise to any discussion.

LITTERA *B*.

" Messrs. HÖNIGSBERG and LE BLANT gave summaries. Mr. Hönigsberg reads the following conclusions, extracted from his report :

" 1° Springs of special steel of high resistance make vehicles run more smoothly and fewer are broken; they require adjustment less frequently, particularly in the cases in which other materials have proved unsatisfactory, or when it has been desired to avoid using reinforced springs for the increased loads.

" 2° In the case of crank axles, special steel is nearly universally used, preferably 5 per cent nickel steel which has given good results, but only when the axles have had a suitable shape.

" 3° Tires of special steel of high resistance are generally used for fast and for powerful locomotives, and for the tenders they haul; often also for other locomotives and in some cases also for passenger stock. The risk of fracture of these tires of high-resistance steel is not great if the tires are tested by impact tests and if they

are fixed by means of a retaining ring. As regards wear, particularly on mountain lines and on curves, it has not yet been possible to ascertain in a general and satisfactory manner whether these kinds of steel are suitable.

" 4° Steels of high resistance are much used for the straight axles of modern locomotives, as well as for the tenders and sometimes also for the carriages; sufficient and uniform data on the subject of these steels are not yet available.

" 5° The use of special steel of hihg resistance for the different parts of the rolling stock is becoming more and more necessary, as the forces acting on them are continually increasing. It is advantageous from the economic point in the case of parts that need renewal frequently, but its use will only develop if it is possible to prove definitely and quickly that such steel is superior in practice, and, as far as possible, to show this by preliminary tests.

" 6° In order to determine the comparative value of different kinds of steel, as regards their behaviour in practice, the general rolling stock statistics do not suffice, except on lines which have uniform rolling stock and uniform working conditions, such as metropolitan railways. It is hence necessary to make special trials under exactly similar working conditions.

" 7° In order to define sufficiently the special steels recognized as superior, it is advisable to make, besides the specification tests, special tests in order to show, as far as possible and directly, the essential qualities of these steels (safety against fracture resulting from blows, unfavourable shape; resistance to wear, etc.). "

" Mr. Le Blant reads the conclusions contained in his report.

" Messrs. Ettenger's and Worsdell's reports did not contain any conclusions, and as these reporters were absent, the meeting decided not to ask to have them read.

" Mr. Kabodi said that his administration did not obtain good results with crank axles made of one piece of nickel steel, but that crank axles made of three forged pieces gave better results.

" Mr. Rohr (*Alsace-Lorraine State Railway*) said that a large number of crank axles made of nickel steel had been in use on the Alsace-Lorraine State Railway for several years and had worked perfectly well.

" Mr. Greppi (*Italian State Railway*) gave some information about crank axles made of nickel steel, of which 779 were in use; with 6 to 8 per cent of nickel the results were not good, while with 5 per cent of nickel, axles showed no cracks, although they had run about 420,000 kilometres (261,000 miles) since 1904. He stated however that the wear at the surface of the journals was not uniform.

" Mr. Antochine (*Russian government*) asked whether any specifications, drawn up by the administrations, existed as to the composition of the nickel steel for crank axles, and whether this was checked.

" Mr. Le Blant (*reporter*) stated that in France metallurgists were given a free hand in order to obtain very hard steel, while eliminating brittleness. The axles were however subjected to physical and chemical tests, and a mileage guarantee was required.

" Mr. KELLER (*Swiss Federal Railway*) stated that his administration had nearly 400 crank axles made of crucible steel and of nickel steel, the latter containing 5 per cent of nickel. The former had not given good results. They became cracked in the outer radius of the crank. The first nickel steel axles had by then run 600,000 to 700,000 kilometres (373,000 to 435,000 miles). The nickel content was not checked by analysis.

" Mr. FOWLER (*Midland Railway*) stated that his administration did not use nickel steel for crank axles, but only a carbon steel with great resistance to fracture. His company had no crank axles made of several parts, but other companies used such axles.

" Mr. LAVIALLE D'ANGLARDS (*Portuguese Railway Company*) asked whether Mr. Greppi could give him any information as to the conditions of manufacture specified to manufacturers of nickel steel axles.

" Mr. GREPPI answered that the chief conditions were : 5 per cent of nickel, an ultimate tensile strength of 55 to 70 kilograms per square millimetre (78,225 to 99,560 lb. per square inch), and an elongation of 18 per cent.

" Mr. KELLER stated that comparisons could only be made with locomotives of the same type and doing the same work. His administration had twenty locomotives of the 4-4-0 type with crucible steel axles, in use since 1897; these locomotives had run at least 600,000 kilometres (373,000 miles) without the axles showing any cracks, but the work of those locomotives was not very heavy. With locomotives of the 4-6-0 type, doing heavier work, cracks had been detected in their crucible-steel axles after they had run not more than 100,000 kilometres (62,100 miles). This circumstance was chiefly due to a defective shape.

" Only two out of two hundred nickel steel crank axles had shown cracks; one of these was still in use after having been repaired.

" Mr. HERDNER (*French Midi Railway*) stated that nickel steel and chrome steel axles had not given satisfactory results, while carbon steel axles, quenched and tempered (gun steel) gave a mileage of 600,000 kilometres (373,000 miles) before cracks appeared. His impression was that the thermal treatment was of greater importance than the chemical composition. In order to obtain trustworthy results, it is necessary to observe axles used for locomotives of the same type.

" He also stated that his company had applied the Frémont process to axles of Worsdell type, but only after the first cracks had been detected. The axles so treated were working satisfactorily.

" Mr. COURTIN (*Baden State Railway*) expressed a similar opinion and stated that he had eliminated the cracks which had been detected in a crank axle by the Frémont process. This axle had run about 60,000 kilometres (37,300 miles) since, and had worked very well.

" Mr. STEINBISS (*Prussian State Railway*) mentioned the tires made of steel manufactured in the electric furnace. This steel was perfectly homogeneous, and had an ultimate tensile strength of 60 kilograms per square millimetre (85,340 lb. per square inch). The results obtained

were as yet not conclusive. Coupling screws and draw-hooks had also been made of this steel.

" The section then agreed to the following text of the conclusions to be submitted to the general meeting. "

The President. (In French.) — The following are the

PROPOSED CONCLUSIONS

LITTERA *A*.

" 1° Steel having an ultimate tensile strength of more than 44 kilograms per square millimetre (62,580 lb. per square inch), is not substituted for the wrought iron, generally used formerly, except for a small number of rolling stock parts, and that only by a few administrations. The forged or wrought iron is more generally replaced by mild steel or ingot iron having an ultimate tensile strength of 33 to 44 kilograms per square millimetre (46,935 to 62,580 lb. per square inch).

" 2° Steel castings are in many cases used to replace wrought iron in the case of parts which are of a complicated shape. They are very generally used as a substitute for cast iron in the case of parts subjected to larger stresses; their use in such cases is intended to increase security.

" 3° It seems however certain that the use of steel will become extended to all locomotive parts. It may be foreseen that steel cars will replace wooden cars, owing to their greater strength, their incombustibility and their less costly maintenance. Cars built entirely of steel make it possible to increase the tonnage while reducing the tare to the minimum compatible with great strength."

LITTERA *B*.

" 1° Many railway administrations use crank axles made of special steel of high resistance, and especially of nickel steel containing 5 per cent of nickel, a metal which has proved satisfactory provided the axles are of proper shape.

" 2° Special steel is used for straight axles only in certain special cases.

" 3° Several railway companies use steel having an ultimate tensile strength of at least 70 kilograms per square millimetre (99,560 lb. per square inch) for the tires of locomotives and tenders. If care is taken to specify impact tests, no fear of fracture need be entertained. "

LITTERÆ *A* AND *B*.

" As it is very probable that the interest in the use of these steels will grow, it is advisable to request the railway systems to undertake trials or to extend the trials already begun, so as to determine as soon as possible the advantages or disadvantages of the use of special steel of high resistance in the construction of locomotives and rolling stock. "

Mr. von Leber, Permanent Commission of the Congress. (In German.) — I would wish to make a short remark on a simple question of wording. It seems to me that our French colleagues do not agree as to the translation of the words " *Schweisseisen* " and " *Flusseisen* ". In the 1st section we also used the words " *fer soudé* " and " *acier doux* ". Now the term " *fer soudé* " has been criticized by

our French colleagues; they think one should simply say " *fer* " and perhaps " *acier doux* ". As I remark that the term " *fer soudé* " occurs several times in the conclusions of the 2nd section, I think that it would be useful to agree as to the term to be used. This difficulty does not arise in German.

Mr. Gerstner. (In French.) — The 2nd section, where I presided, also has considered this point. We have used the term " *acier doux* " for what is called in German " *Flusseisen* ". In order to designate the metal which this mild steel is to replace, we used the term generally used in French. The term " *fer soudé ou forgé* " well shows how this metal is made. I see, however, no objection to striking out the two descriptive words, for every French engineer will at once understand what we mean.

Mr. Bélélubsky, Ministry of ways of communication, Russia. (In French.) — I think it very important to retain in conclusion 1, littera *A*, the words " *acier doux ou fer fondu* ", which designate the same kind of metal. There are in fact countries where the former expression is used, in France for instance, while in other countries, for instance Russia, the latter is always used, " *Flusseisen* " being invariably translated by the words " *fer fondu* ". The 1st section which considered question II also made use of both terms.

Mr. Gerstner. (In French.) — I have not proposed to strike out either of these terms. I have only agreed to striking out the words " *forgé ou soudé* ".

Mr. Cartault, Paris-Lyons-Mediterranean Railway. (In French.) — We have in French only the two words " *fer* " and " *acier* ", and the 1st section, in the conclusions it has adopted, merely speaks of " *fer* " without adding the words " *fondu* " or " *forgé* ", and of " *acier doux* ". In France, the words « *fer fondu* » would suggest cast iron.

I entirely agree with Mr. von Leber; it would be better to use in the French text only the words " *fer* " and " *acier* ". Then no confusion would result.

The President. (In German.) — The reporter states that he accepts Mr. von Leber's proposal. Is the wording proposed by the section retained?

Mr. Gerstner. (In German.) — I have proposed to strike out in the French text the two words " *forgé* " and " *soudé* ". On the other hand, in order to meet the objections raised by Mr. Bélélubsky, and considering the non-French countries which more or less adopt the German terminology, I should like to retain the two terms " *acier doux* " and " *fer fondu* ".

The President. (In German.) — Then we retain the proposal of the section, as it stands?

Mr. Gerstner. (In German.) — No, we must strike out the two words " *forgé* " and " *soudé* " in the conclusion 1, littera *A*.

The President. (In French.) — Then the following are the final conclusions :

CONCLUSIONS.

Littera *A*.

" 1° Steel having an ultimate tensile " strength of more than 44 kilograms per

" square millimetre (62,580 lb. per square " inch), is not substituted for the wrought " iron, generally used formerly, except " for a small number of rolling stock " parts, and that only by a few adminis- " trations. The iron is more generally " replaced by mild steel or ingot iron " having an ultimate tensile strength of " 33 to 44 kilograms per square milli- " metre (46,935 to 62,580 lb. per square " inch).

" 2° Steel castings are in many cases " used to replace wrought iron in the case " of parts which are of a complicated " shape. They are very generally used " as a substitute for cast iron in the case " of parts subjected to larger stresses; " their use in such cases is intended to " increase security.

" 3° It seems however certain that the " use of steel will become extended to all " locomotive parts. It may be foreseen " that steel cars will replace wooden cars, " owing to their greater strength, their " incombustibility and their less costly " maintenance. Cars built entirely of steel " make it possible to increase the tonnage " while reducing the tare to the minimum " compatible with great strength. "

Littera *B*.

" 1° Many railway administrations use " crank axles made of special steel of high " resistance, and especially of nickel steel " containing 3 per cent of nickel, a metal " which has proved satisfactory provided " the axles are of proper shape.

" 2° Special steel is used for straight " axles only in certain special cases.

" 3° Several railway companies use " steel having an ultimate tensile strength " of at least 70 kilograms per square " millimetre (99,560 lb. per square " inch) for the tires of locomotives " and tenders. If care is taken to specify " impact tests, no fear of fracture need " be entertained."

Litteræ *A* and *B*.

" 1° As it is very probable that the in- " terest in the use of these steels will " grow, it is advisable to request the rail- " way systems to undertake trials or to " extend the trials already begun, so as to " determine as soon as possible the ad- " vantages or disadvantages of the use of " special steel of high resistance in the " construction of locomotives and rolling " stock.

" 2° It would be desirable that the " specification tests should be made in " accordance with the rules of the Inter- " national Association for testing mate- " rials."

— These conclusions were adopted.

SECTION II : LOCOMOTIVES AND ROLLING STOCK

[621 .133.5, 621 .133.7 & 621. 134.3]

QUESTION VI

IMPROVEMENTS IN LOCOMOTIVE BOILERS

A. *Boilers with smoke tubes. Precautions in constructing and maintaining tubes and tube-plates.*

B. *Boilers with water tubes. Steam superheaters and valve gear for superheated steam. Feed water heaters.*

C. *Damages to boilers, blisters, cracks and corrosions. Means employed for preventing these damages. Purification of the water and disincrustants or antifouling compounds.*

Reporters :

Russia. — Litteras *A* and *C*. — Mr. N. Antochine, engineer of technology and of ways of communication, member of the technical council of the ministry of ways of communication of Russia.

America. — Litteras *A* and *B*. — Mr. H. H. Vaughan, assistant to vice president, Canadian Pacific Railway.

Austria, Hungary, Rumania, Turkey, Servia and Bulgaria. — Littera *B*. — Mr. Franz Gerstner, State councillor, inspector-general and superintendent of the rolling stock and locomotive department of the Austrian State Railway.

Russia. — Littera *B*. — Mr. G. Noltein, engineer, member of the administration of the Moscow-Kazan Railway Company.

France, Belgium, Italy, Spain and Portugal. — Littera *B*. — Mr. C. Dassesse, chief engineer to the locomotive and rolling stock department of the Belgian State Railway.

Austria, Hungary, Rumania, Turkey, Servia and Bulgaria. — Litteras *A* and *C*. — Mr. Johann Papp, councillor of State, chief inspector and head of the locomotive department of the Hungarian State Railway.

France, Belgium, Italy, Spain and Portugal. — Litteras *A* and *C*. — Mr. Nadal, chief engineer, French State Railway.

Great Britain. — Litteras *A*, *B* and *C*. — Mr. H. Fowler, locomotive works manager, Midland Railway, and Mr. L. Archbutt, chemist, Midland Railway.

Other Countries. — Litteras *A*, *B* and *C*. — Mr. K. Steinbiss, member of the Board of works of Prussia.

QUESTION VI

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Report No. 2 (litteras *A*, *B* and *C*) (Australasia, Great Britain, India and South Africa), by Messrs. H. FOWLER and L. ARCHBUTT. (See English edition of the *Bulletin* of October 1909, p. 1127.)	VI — 31
Report No. 5 (litteras *A* and *B*) (America), by Mr. H. H. VAUGHAN. (See English edition of the *Bulletin* of February 1910, p. 607.)	VI — 127
Report No. 4 (littera *B*) (Austria, Hungary, Rumania, Bulgaria, Servia and Turkey), by Mr. Franz GERSTNER. (See English edition of the *Bulletin* of March 1910, p. 1037.)	VI — 175
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N. B. — Vide also the separate issues (in red cover) Nos. 1, 8, 29, 34, 39, 46, 47, 52 and 57.

[621 .133.3 & 621 .133.7]

REPORT N° 1

(Belgium, Spain, France, Italy and Portugal)

By Mr. NADAL,

CHIEF ENGINEER, FRENCH STATE RAILWAYS.

The detailed list of questions referring to subject VI, sections *A* and *C*, drawn up by the English reporters, Messrs. Fowler and Archbutt, is reproduced in the appendix.

In the following report, the paragraphs are numbered so as to correspond to the questions.

Subject VI, section *A*.

1. *Type of boilers.* — The chief French railways have adopted Belpaire boilers on all their more recent locomotives, but the Paris-Lyons-Mediterranean is designing a Pacific Lomotive with a round-topped boiler. The same applies, since 1898, to the system of the Belgian State Railway, on which only a few compounds have Belpaire fire-boxes. The Spanish and Portuguese systems, as well as the secondary railways of all the countries concerned, use both systems.

Each of these two types of fire-boxes has its own advantages and disadvantages, and these have been the subject of much discussion. It must finally be recognized that neither the one nor the other is very definite, but the round-topped fire-box is more extensively used, and it appears to be preferable in the case of large boilers.

2. *Fire-box stays.* — The round-topped boilers of modern locomotives have, just like the Belpaire boilers, vertical and transverse stays of steel or of iron; only a few

secondary railways still use roof bars. The general opinion is that stays have the following advantages over roof bars : they are lighter and of simpler construction; they hold the fire-box crown and the outer shell together with more certainty; the formation of scale on the crown is less; examination and cleaning are more easy. On the other hand, roof bars have the advantage of allowing the fire-box to expand more freely and of reducing the deformations and the chances of fracture in the upper corners of the tube-plate. In order to facilitate the expansion of this plate in cases where stays are used, one or preferably two rows of expansion stays should be used in the front part.

3 and 4. — *Cylindrical fire-boxes, combustion chambers.* — No railway has boilers with cylindrical fire-boxes or with combustion chambers.

5. *Steel fire-boxes.* — The fire-boxes are made of copper, but several railways have tried or are at present trying fire-boxes made wholly or partly of steel.

The French Northern has lately fitted two locomotives of older design with fire-boxes made wholly of steel. This application is too recent to enable any conclusions to be drawn as yet.

The Midi has fitted a considerable number of locomotives with fire-box crown sheets made of steel plate; these have given good results and afford satisfaction.

The Paris-Lyons-Mediterranean has tried, a dozen years ago, fire-boxes made wholly of steel; the results were not satisfactory owing to the cracks which very quickly formed in the stayed portions.

During the last two years, the French State Railway has been trying, on two locomotives having working pressure of 13 kilograms per square centimetre (185 lb. per square inch) and on one having working pressure of 15 kilograms (213 lb.), tube-plates with that part which receives the tubes, made of steel and the lower part made of copper. These two parts of the tube-plate are joined by a lapped seam, the copper being on the side towards the fire, so that it can be caulked; the seam is a little higher than the arch. These compound plates have up to the present given good results; leaks have however occurred at the seam, which have been stopped by caulking and have made it necessary to replace some of the rivets.

The Italian State has had American locomotives with fire-boxes made wholly of steel, similar to those used in America, *i. e.* made of comparatively thin plate : 12·7 millimetres ($^1/_2$ inch) for the tube-plate and 9 millimetres ($^{11}/_{32}$ inch) for the other parts. The results have not been satisfactory.

Finally, the Great Southern of Spain (the Lorca-Aguilas line) fitted, as an experiment, two boilers in 1907 with steel tube-plates; as these gave satisfactory results, it was decided to try fire-boxes made wholly of steel; the first was taken into use in August 1908.

6. *Fire doors.* — The fire doors used nearly universally work on hinges, and are

elliptical or rectangular with the corners rounded; some are round. The air admission can often be regulated by means of a grid or a flap valve. Their width varies from 290 to 350 millimetres from 11 7/16 inches to 1 ft. 1 3/4 in. and their height from 390 to 450 millimetres (from 1 ft. 3 3/8 in. to 1 ft. 5 3/4 in.).

The Orleans Railway has adopted on its Pacific locomotives the type of large front with triple door opening inwards; the width is 700 millimetres (2 ft. 3 9/16 in. and the height 380 millimetres (1 ft. 3 in.). This seems to be an excellent type of door for locomotives with large fire-boxes.

The fire-box plates and the shell and the opening are always joined together by means of a riveted ring.

7. *Relation between the grate area, air-space in the fire grate, and total tube-area; rocking grates.* — The air-spaces in the fire grate are as a rule equal to about half the total area of the grate; on some railways, this ratio varies between one half and twofifths; in some cases, it is reduced to 0·35, particularly if rocking grates are used. This type of grate, which is very common in America, is beginning to become more usual in Europe; the Orleans Railway has adopted it on its more recent locomotives and so has the French State Railway; the Midi and the Paris-Lyons-Mediterranean have equipped several locomotives with this device as an experiment. Rocking grates seem to give very good results; they make it easy to clean the fire while saving the fireman from the troublesome handling of the firing tools.

The total clear cross-section of the smoke tubes varies between a sixth and an eighth of the grate area. This cross-section can hardly be too large; increasing it reduces the speed of the current of hot gases and consequently reduces the amount of fuel (solid or gaseous) which is drawn over into the smoke-box, without being burnt. The clear cross-section can be increased either by increasing the diameter of the tubes (for it is easy to see that with a given area of tube-plate, the cross-section of the tubes is increased by increasing the diameter , or by adopting the American « wagon top » form, by means of which the tube-plate of the fire-box can be given a greater useful surface, better proportioned to that of the tube-plate of the smoke-box.

The heating surface of the tubes varies between fifty and seventy times the grate area, if smooth tubes are used, and between sixty and eighty times the grate area, if Serve tubes are used. Increasing the heating surface of the tubes to beyond a certain limit (which, in the case of smooth tubes, can be fixed at about fifty to sixty times the grate area), is of very little advantage as regards the efficiency of the boiler. In fact, even if the heating surface of the tubes is very much increased, all that can be attained is to reduce by some 50°, that is by one sixth at most, the temperature of the hot gases in the smoke-box, which varies normally, according to the intensity of the combustion, between 300 and 350° C. (between 570 and 660° Fahr.). Now the heat lost by the gases in the smoke-box represents about 15 per cent of the total heat produced by the combustion of the fuel. If this loss is reduced by one sixth, the

amount of heat utilized, that is to say, the efficiency of the boiler, is only increased by 2·5 per cent.

8. *Intermediate supports for the barrel and for the tubes.* — Generally speaking, except in the case of Pacific locomotives which are as yet few in number, the length of the barrel does not exceed 5 metres (16 ft. 5 in.). The smoke-box is rigidly fixed to cross-bracing connecting the frame plates. On some railways, the barrel has no other support, but most of them use intermediate supports which are formed either of flexible plate, according to the American plan, or of cross-bracing formed of steel castings, on which the boiler can slide. This plan is adopted, and with still better reason, on the Pacific locomotives, which have barrels about 6 metres (19 ft. 8 in.) long.

It may be asked whether, in the case of long boilers, the tubes, which are subject to vibration and to bending, do not require to be supported by an intermediate tube-plate. This has sometimes been done in the case of old locomotives, but it has been found to be useless. This uselessness is very definite if ribbed tubes are used, which are very stiff, smooth tubes having a greater outside diameter than 50 millimetres (1 $^{31}/_{32}$ inch) are also sufficiently stiff, and there is a tendency to use, in the case of long boilers, tubes having a diameter of at least 55 millimetres (2 $^{5}/_{32}$ inches).

9. *Tube-plates in the smoke-box.* – Nearly all the railways use a drum-head tube-plate in the smoke-box; this is riveted to the inside of the front ring of the barrel. Some, especially the Belgian State and the Andalusian, also use a plate with extension fitted to the barrel with an angle.

10. *Material of the smoke tubes.* — The smoke tubes are made of iron, of mild steel or of brass.

In France, mild steel is nearly exclusively used, and for the following reasons :

Mild-steel tubes cost less than brass tubes;

They produce smaller strains in the tube-plates, because the coefficient of expansion of steel is less than that of brass;

Brass tubes do not resist pressures of over 12 kilograms per square centimetre (170 lb. per square inch) satisfactorily;

The ends of the steel tubes are very easily repaired by autogenous-soldering methods;

The fire-box ends of tubes made wholly of brass are rapidly corroded; safe-ends of copper and ferrules have to be added; these ends are expensive and give rise to fracture.

It is true that steel tubes become pitted and corroded more quickly than brass tubes, if the water is of bad quality, but the results of this disadvantage are of but little importance in France where the water is, as a rule, of good quality.

The Algerian railways prefer brass tubes because they resist corrosion better; the water in Algiers is of bad quality.

The Italian railways use brass for smooth tubes less than 4·400 metres (14 ft. 5 1/4 in.) long, and iron or steel for longer tubes, on account of the injurious effect due to the expansion of the long brass tubes.

The Belgian railways use brass because the water is often of poor quality. In order to avoid expansion effects, the tubes are slightly curved upwards, and the tube-plates are held together by steel stays.

The question of whether steel or brass is to be used, depends in fact on the quality of the water.

11. *Dimensions of the smoke tubes.* — The length of the Serve tubes, which are nearly exclusively used on the locomotives built in France during the last ten years or so, varies between 3·500 and 4·500 metres (between 11 ft. 6 in. and 14 ft. 9 in.). The more recent Pacific locomotives have smooth tubes about 6 metres (19 ft. 8 in.) long, and having an external diameter of 55 or 57 millimetres (2 5/32 or 2 1/4 inches). The external and internal diameters of the Serve tubes are, as a rule, 70 and 65 millimetres (2 3/4 and 2 9/16 inches) respectively.

The locomotives of the older types have smooth tubes of a length seldom exceeding 5 metres (16 ft. 5 in.); the most usual external diameter is 50 millimetres (1 31/32 inch). The same applies to both older and more recent locomotives on the foreign railways. In addition to the diameter of 50 millimetres (1 31/32 inch), diameters of 45, 48, 52 and 53 millimetres (1 25/32, 1 7/8 inch, 2 1/16 and 2 3/32 inches) are also used.

The tubes are contracted 2 to 3, and sometimes 4 millimetres (3/32 to 1/8, and sometimes 5/32 inch) at the tube-plate of the fire-box and expanded 2 to 3 millimetres (3/32 to 1/8 inch) at the tube-plate of the smoke-box.

12. *Fixing the tubes.* — The tools used for fixing the tubes in the plates are the Dudgeon, the Caraman and the Boyer. They are sufficiently well known to make it unnecessary to give a description of them.

The holes have as a rule a taper of 1 in 40 or 1 in 50, and the drift of the tube expander has the same taper, so as to make a conical joint which helps to secure the tube to the plate. At the fire-box end the expanding is generally done in two operations, one before and one after the beading of the tube end.

The order in which the tubes are successively set in varies much on different railways, and this seems to show that it is of no importance. On the French Eastern, the tubes are set in and expanded in horizontal rows, alternately from right to left and from left to right. On the French Northern, the work is done in vertical rows, starting from the middle, and then doing a vertical row on the right and on the left alternately, but always going from the top to the bottom; experience would show that this method, which tends to drive the metal towards the edges, is the best for

avoiding deformations of the tube-plate. On the Midi Railway, the work is done in horizontal rows, starting from the bottom. On the Paris-Lyons-Mediterranean, the work is done in vertical rows, starting from the extreme left or the extreme right row; but always starting at the top. On the Belgian State Railway, no particular order is adopted.

Small importance need apparently be attached to the order in which tubes are set in, but the most rational procedure would seem to be that of the Northern Railway; if however it is advisable to drive the metal towards the side edges of the plate in order to avoid deformation, it would appear to be equally advisable to drive the metal towards the upper edge, and then the work should be done in vertical rows, starting from the centre and always from the bottom to the top.

13. *Serve tubes.* — The French railways use Serve tubes nearly exclusively; the Italian railways also use them extensively. It is generally recognized that they give good results as regards steam-generation, but several railways, more especially the Eastern, the Midi and the Italian State, think that these tubes, owing to their excessive rigidity, accelerate the deterioration of the fire-box tube-plates.

The Belgian State Railway tried in 1896 Serve tubes on locomotives with large Belpaire fire-boxes with a grate area of 4 to 5 square metres (43 to 54 square feet); the results were unsatisfactory; the tube-plates became deformed and cracked by thrust of the tubes. They have again been used on some sixty compound four-cylinder locomotives with narrow fire-box; the tube-plates, which are held together by four stays, have resisted well up till now. No appreciable difference in power or in consumption has been observed between locomotives of the same kind equipped, some with Serve tubes, others with smooth tubes.

14. *Damage to tubes.* — With good water, pitting or corrosion of steel tubes is very rare and gives no trouble. On the other hand if the water is bad, such phenomena appear very quickly and it is better to use brass tubes. But with these another trouble arises namely : wear at the fire-box end, and fractures just inside the tube-plate. The wear is especially quick if the ends of the tube are not pieced with copper; in order to mitigate matters, steel ferrules are used, both when the ends are pieced with copper and when not.

Galvanized steel tubes have been tried by the French Eastern in districts where, owing to the quality of the water, much scale was produced and there was much corrosion. No difference, from any point of view, was observed between galvanized tubes and ordinary tubes.

The Italian State Railway has recently started trying corrugated steel Mannesman tubes, and tubes of galvanized steel.

15. *Ferrules, beading the tubes.* — The railways which use steel tubes do not use ferrules, while those which have kept to brass tubes apply ferrules in order to pro-

tect the end of the tube against the fire and to improve the tightness. The thickness of the ferrules varies between 2·5 and 4 millimetres (between $^{3}/_{32}$ and $^{5}/_{32}$ inch ; their taper is the same, or is a little greater, than that of the holes in the tube-plate. Ferrules have the great disadvantage that they materially reduce (at least by 10 to 12 per cent in the case of smooth tubes) the clear cross-section available for the hot gases, and consequently the steam-generation. On the other hand, they cannot be much depended on for increasing the tightness, for they easily work loose and get knocked out of place by the cleaning rods. As regards protecting the ends of the tubes, they are very efficient.

The steel tubes are nearly everywhere beaded over, at all events at the fire-box end, and often also at the smokebox end. The bead at the end of the tube increases its strength, prolongs its life and protects the tube-plate of the fire-box against the direct action of the hot gases at the joint. As leaks always start at the edge of the holes, it is very important to protect this spot by beading over the tube end. Finally, such beaded tubes are much less liable to become clogged; soot and other solid particles are much less likely to collect there; such matter would tend to obstruct the tubes more or less, and would materially interfere with the passage of the hot gases and consequently with the steam-generation.

In the case of brass tubes, the practice of beading is less general. On the Belgian State Railway, the brass tubes are beaded, while this is not done on the Italian railways and on most secondary railways. But the Italian railways have now for some time been trying special ferrules with a flange, in order to protect the ends of the copper tubes against the flames, and this would show that such a protection is considered necessary.

15[bis]. *Leaks in the tubes.* — The causes to which the administrations of the different railways attribute leaks in the tubes are many and various, but they are of very unequal importance. In the first place, there are mechanical causes : bad execution of the work in setting in the tubes at the beginning, and bad maintenance ; in particular, bad expanding and bad beading. It is evident that very careful work is to be recommended, but it must be remarked that the work, even if not well done, seldom results in producing leaks at the tube-plate of the smoke-box. There is no reason why a different result should be obtained at the fire-box tube-plate, were it not that other causes also contributed towards the production of leaks. Consequently, care in executing the work of setting in the tubes has after all only an influence of secondary importance.

Then we have the different physical causes : expansion and contraction phenomena, unequal variations of temperature, incrustations.

As the tubes are at a higher temperature than the barrel, they expand more, and consequently exercise a thrust on the tube-plates, which makes itself felt more particularly at the fire-box tube plate, as this is less firmly secured than the smoke-box tube-plate. The expansion of the fire-box tube-plate itself tends to deform it in its

plane; the bottom of this plate is secured more firmly than its top and consequently tends to become deformed along two diverging lines going towards the upper corners, and is subjected to compression in these directions; this is proved by the ovalisation of the holes for the tubes, which show a larger diameter at right angles to these directions; this phenomenon has been observed on a number of copper tube-plates. The different effects of the ovalization of the holes, of the thrust of the tubes perpendicularly to the tube-plate, of the contraction of the tubes along their diameter, due to the fact that the temperature of the ends at the fire-box tube plate is somewhat higher than that of the body of the tubes which are surrounded with water, bring it about, after a certain time, that the limit of elasticity is exceeded and that the tubes are no longer as tight in the plate as when they had just been expanded and beaded over. In other words, the smoke tubes have, neither longitudinally nor transversely, the same expansion as the fire-box tube-plate; it naturally follows that the joint must sooner or later work loose. That is probably what really happens in the majority of cases when leaks start. Evidence in favour of this explanation is given by the fact that leaks are very rare in the case of new tubes. These different effects are moreover much increased by any incrustations, which may materially increase the difference of temperature between the tube-plate and the water, a difference which normally amounts to only a few degrees.

Such phenomena, which are inherent to the materials actually used and to the quality of the water, cannot be overcome except by methodical renewals of half or all the tubes, effected by preference at regular intervals, which will be longer or shorter according to the quality of the water, or at least effected as soon as leaks result from the strains in the tubes. Experience shows that if leaks occur with new tubes, tightening them once suffices, while if they appear in the case of fatigued tubes, where the limit of elasticity has been exceeded, fresh tightening may make it possible to run a few days longer, but in reality only aggravates the evil and there is no really effective measure except to put in fresh tubes, and naturally at the same time the holes in the tube-plate must be made circular again.

Then also precautions have to be taken to reduce any phenomena resulting from the sudden contraction of the boiler. The fire-box cools too quickly if the fire is drawn at the end of a journey; it would be desirable to let it go out slowly. Emptying the boilers when hot and washing them out with cold water also tend to produce sudden and unequal contractions. The proper amount of time should be devoted to these operations; the boilers should not be washed out with cold water until they have become completely cooled; washing should be done as far as possible with hot water; and even in this case, as hot water is seldom at a higher temperature than 50 or 60° C. (122 or 140° Fahr.), the boiler should first be allowed to cool sufficiently.

While on a journey, unequal variations of temperature due to bad management of the firing and of the supply of water may also, under certain conditions, that is to say, if the tubes are not in perfect condition, result in leaks. Moreover, if such

bad management were the usual thing, the tubes, even if perfect at the start, would very soon suffer.

Mr. E. Wells, assistant master mechanic, Wheeling & Lake Erie Railroad, in a very noteworthy paper (1) on the causes of leaks in boiler tubes, states that the principal cause of such leaks consists in the prolonged injection of cold water into the boiler while the regulator is closed, on down gradients, during stops, and at the end of the run; the comparatively cold water, 80° C. (176° Fahr.) at most, sent in by the injectors at once goes to the bottom of the boiler, and if much enters and the fire is not brisk, it materially cools the lower tubes; unequal variations of temperature result and leaks start at the lower tubes. It has in fact been observed for a long time that leaks nearly always start there. Mr. Wells has even observed that if one injector only is as a rule used, it is at the lower tubes on the injector side that leaks occur.

It must be observed, as regards the starting of the injectors when running downhill and during stops, that this is certainly the practice of most drivers; this is what is called utilizing the gradients for taking water; however, leaks in the tubes do not always result.

Mr. Wells disputes the influence of successive heating and cooling on the play resulting between the tubes and the plates. (It must however be remembered that he is considering American fire-boxes which are made entirely of steel). In order to prove this, he took a piece of tube having a diameter of 57 millimetres (2 1/4 inches) and set it in a plate 12·7 millimetres (1/2 inch) thick; he then by means of a gas furnace heated it to 220° C. (428° Fahr.) and then cooled it; these operations were repeated a number of times without any play resulting between the tube and the plate. But this experiment is not conclusive, because the piece of tube tried was not under the same conditions as the boiler tubes, which are held at the two ends and hence necessarily excercise thrusts on the tube-plates. As the second argument in favour of his contention, Mr. Wells mentions the fact, observed in practice that leaks nearly always occur at the tubes of the lower rows, the upper rows remaining tight, although experiments made in which fusible metal was placed at different points on the tube-plate showed that neither the tube-plate nor the tubes were hotter in the lower parts than in the upper parts; consequently something else than the heating and the cooling of a tube is necessary in order to produce play, and this other cause is the cooling of the individual lower tubes produced by the feed water.

It is certain that the lower tubes leak more frequently than the upper, and the influence of the feed water cannot be denied, but is this the only influence? Is it even the most important factor? This would seem to agree but badly with the other observation, also made in practice, that copper tube-plates often become bent inwards; and when this happens, it is nearly always the lower portion which

(1) Paper presented at the annual convention of the American Railway Master Mechanics' Association. June 1907. (Vide *Bulletin of the Railway Congress*, No. 1, January, 1908, p. 88.)

becomes so bent. This bending cannot be attributed to the arrival of the feed water, and just like the play between the tubes and the plate, which may be looked upon as its consequence, it is rather the result of the relative deformations of the plate and the tubes.

Mr. Wells also disputes the influence of the entrance of cold air, seeing that the temperature of the tube-plate, at least if there is but little incrustation, is only a few degrees higher than the temperature of the water, that an entrance of cold air cannot appreciably reduce the temperature of that tube-plate, and more especially cannot make it fall to below that of the water. These are perfectly definite facts, and the entrance of cold air, unless it is localized and very prolonged, can only have a secondary influence. It is however well recognized that brick arches, which protect the tube-plate against such entering air, excercise a beneficial influence on the condition of the tubes.

In order to prevent leakage at the tubes, some companies, in addition to the precautions mentioned above as to the management, the maintenance and the washing of the boilers, have tried special arrangements.

The French Northern has tried expansion smoke tubes, the front ends of which pass through a stuffing-box fixed to the smoke-box tube-plate. But the use of such stuffing-boxes, even if they allow the tubes to expand, do not remedy the loosening which results from the transverse expansion of the tube-plate of the fire-box. This trial has not been extended. Then also, in a number of its more recent locomotives, the French Northern has placed the end of the feed-water pipe in the steam.

The Midi is at present trying to prevent the leaks by sending the feed water into a tank placed above the level of the water and in the front of the boiler.

Several French railways, in order to reduce the giving of the interspaces and the ovalization of the tubes, which nearly always begin at the upper corners of the fire-box tube-plate, reduce the diameters of the tubes placed there, so as to increase the magnitude of the interspaces.

The Italian State is at present trying the use of an injector of reduced size capable of supplying water continuously, the preliminary heating of the feed water and the installation of the Gölsdorf water-softening apparatus, which consists of a flattened box, placed vertically between the barrel and the nest of tubes in which the feed-water pipe ends.

It may be remarked that it is not as a rule necessary to adopt injectors of reduced size in order to ensure a continuous feed, for with the modern re-starting injectors of the usual size, the amount of water given may be varied from normal to practically double by adjusting the water valve. It would be eminently desirable to give the feed water a preliminary heating either by means of the exhaust gases or of the smokebox gases; various attempts in this direction have been made or are being made; unfortunately, the appliances required for the purpose are very complicated and no good solution of the question has as yet been obtained.

Finally, the quality of the water is one of the principal factors determining

the production of leaks at the tubes; this will be considered more in detail in section C.

16. *Arrangement of the tubes in the tube-plate.* — Except on some Spanish railways, the tubes are always arranged in vertical rows; it is the general opinion that this arrangement facilitates the disengagement of the steam, the washing and the need of cleaning; scale appears to form less readily than if the rows are horizontal.

The Serve tubes having an external diameter of 70 millimetres (2 3/4 inches) are spaced 89 to 90 millimetres (3 1/2 to 3 9/16 inches) apart, centre to centre; the smooth tubes having an external diameter of 50 millimetres (1 31/32 inch), 67 to 70 millimetres (2 5/8 to 2 3/4 inches). The tubes are contracted by from 2 to 4 millimetres (from 3/32 to 5/32 inch) at the fire-box tube plate, which increases the interspaces in between, to the same extent.

17. *The use of high pressures.* — In France, nearly all the locomotives constructed during the last ten years or so have a working pressure of 15 or 16 kilograms per square centimetre (213 or 228 lb. per square inch). Special means to cope with these pressures, especially in the keeping of the tubes tight and in maintaining the fire-box tube-plate are not taken. The Midi, in the case of its more recent locomotives, has connected the two tube-plates by stay rods placed with the tubes.

The foreign railways also, but not so generally, use pressures of 14 to 16 kilograms per square centimetre (199 to 228 lb. per square inch).

It has everywhere been observed that boilers with a higher pressure suffer sooner and require more maintenance than the old boilers, with a working pressure not exceeding 12 kilograms per square centimetre (170 lb. per square inch). It may be asked whether this result is wholly due to the increase in pressure, or whether it is due to any other cause, at least partly and to an extent that can as yet not be determined. For at the same time as the working pressure, the size of the fire-box has also been increased, and that in one dimension only, namely longitudinally; for nearly all the fire-boxes are in between the frame plates and are consequently all of the same width. Now it is evident that increasing the magnitude of the fire-box in the longitudinal direction only has the effect of increasing the thrusts due to expansion. It consequently remains to be ascertained whether a large, wide fire-box, extending above the frame plates, and having a similar cubical content to the old fire-boxes, will not be stronger than a large, narrow fire-box. If this were so, it would show that the increase of the pressure is only of secondary importance.

18. *Influence of the spacing of the tubes and stays on damages of tube-plates. Cold hammering of the tube-plates.* — Several railways reply that the spacing of the tubes and stays has no influence on the production of cracks in the corners of the tube-plates. However, it seems advantageous to have as large a radius as possible, and this leads to having the extreme vertical rows of tubes and stays at some distance

from the edges of the plates. It is also advisable, in order to avoid fractures of the interspaces between the tubes, to have the centres of the tubes as far apart as possible, or else to contract the ends of the tubes at the fire-box tube-plate more than is usual; this also facilitates the circulation of the water and the disengagement of the steam, which is particularly brisk at the tube-plate. Most of the French railways, in the case of Serve-tube boilers, reduce by 6 to 8 millimetres ($^1/_4$ to $^5/_{16}$ inch) the diameter of twelve to fifteen tube holes in each upper corner of the tube-plate.

Fire-box tube-plates of copper are generally hammer-hardened by the cold hammering of the parts where the tubes enter; as a result, the tubes are held better, the tightening produced by the expanding being more effective.

18bis. *Methods for repairing the tube-plate.* — The chief injuries in tube-plates are cracks in the corners and fractures in the interspaces. In order to repair the former, copper angles are applied after removal of the part damaged; in the case of the latter, screwed copper rings are put in, expanded and beaded over; if the fracture extends from one hole to another, either an 8-shaped piece is applied, or else a stud is screwed into the damaged place before the copper rings are put in.

Several railways use the Ragno system (1); in this a thin copper sheet, 2 to 3 millimetres ($^3/_{32}$ to $^1/_8$ inch) thick, is placed on the inside of the tube-plate to which it is shaped, and is kept in place by ferrules placed in the tube holes and beaded over on both sides.

19. *Extended smoke-boxes.* — The length of the smoke-boxes of the newer French locomotives varies between 1·785 and 2·100 metres (between 5 ft. 10 $^1/_4$ in. and 6 ft. 10 $^5/_8$ in.). The smoke-boxes on some older locomotives have been made larger. The smoke-boxes of the Belgian State Railway have a maximum length of 1·900 metres (6 ft. 2 $^{13}/_{16}$ in.). Most of the foreign railways also have smoke-boxes of large size.

This increase of capacity has the advantage of making more uniform the vacuum produced by the exhaust, of giving the hot gases a large cross-section for their passage while at the same time making it possible to reduce the size of mesh or the clear spaces between the wires of the metal screens used to arrest sparks, and of providing room for the cinders to settle without obstructing the lower tubes.

20. *Steam domes.* — All the locomotives have steam domes, even the Pacific locomotives which have the centre line of their boilers 2·900 metres (9 ft. 6 in.) above rail-level.

21. *Lagging the boilers.* — As a rule, the insulating material simply consists of a layer of air; the boilers are surrounded everywhere, except at the lower part of the

(1) Vide *Bulletin of the Railway Congress*, No. 7, July, 1907, p. 709.

fire-box beyond the frame plates and below, by thin
frame, 35 to 40 millimetres (1 3/8 to 1 9/16 inch) from th

A certain number of railways have made trials of lagg

The French Eastern tried, in 1872, cork lagging a
in 1887-1889, an asbestos lagging which was used on eighty-f
in 1890-1892, a silicate-cotton lagging which was used on sixteen l
conclusion drawn from these trials was as follows : " Taking into c
small saving which one can hope to effect and the disadvantages wh
presents as regards the maintenance of the boilers, it is advisable t
locomotives with such non-conducting coverings ".

The French Northern has, as a trial, used asbestos lagging on two 4-4-
of the latest type and on a tank locomotive, with six coupled wheels, of
Railway. These laggings, when examined sixteen and twenty-four mo
wards, were found to be in good condition. But it was not possible to
the saving owing to the difficulty of disentangling all the other factors whi
more material effect on the consumption. These solitary applications have n
extended. The use of lagging has disadvantages if the boilers are washed ou
cold water. As the boiler cools more slowly, there may not be time availab
wait till it is quite cold. Now, as we have seen above, this is one of the cause
leaky tubes.

The Midi is at present making trials with a lagging consisting of magnesium carbonate. The saving in fuel resulting from the use of such lagging is stated to be 2 to 3 per cent.

The Paris-Lyons-Mediterranean is trying various kinds of lagging, but states that it has as yet not determined their value.

The Italian State Railway is also trying various laggings: magnesia, white asbestos, blue asbestos from the Cape.

The Belgian State Railway uses, as a general rule, a non-conducting covering consisting of asbestos matting covered over with thin sheet iron. The back of the fire-box is protected by boards with a coat of silicate paint, also covered by thin sheet iron. On some tank locomotives, the inside of the roof of the cab is also lined with boards.

Comparative trials made with locomotives with asbestos lagging and locomotives with simple sheet-iron lagging, have not made it possible to determine the saving in fuel. It has, on the other hand, been observed that locomotives with lagging take on the average three hours longer to cool than those which have no lagging.

22. *Thermal storage.* — No railway uses any system of thermal storage.

CONCLUSIONS

n, France, Italy and Portugal are concerned.

rds the construction of fire-tube boilers are;

bppe. . boxes;
n the fire-boxes;
of rocking grates;
steel tubes, except where the water is bad;
.vour with which ribbed tubes have been regarded during the last

ón of means for reducing leakage at the tubes and damage to the
nout any definitely-successful results having yet been obtained in this

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SUBJECT VI, SECTION *C*.

ftening processes, treatment. — The French railways, except the Northern, ıtening processes but little, for the waters are generally of satisfactory quality. Northern on the other hand, purifies about one third of the water it uses by ans of intermittent or continuous apparatus in which lime or soda is used.

The Italian State Railway only has three stations where water is purified, the Belgian State only two; the Spanish railways have also but a few.

In Algiers, owing to the very bad quality of most of the water, purifying processes are a necessity. The purification is effected with lime and with soda by means of intermittent apparatus or continuous apparatus on the Desrumeaux system. According to the very interesting and very complete information supplied by the Bône-Guelma Company, the composition of the water shows sudden variations due to changes in the weather. In order to obtain good results, it is absolutely necessary to make frequent analyses of the water which is to be treated, of the lime used and of the purified water. The laboratories receive samples of the natural water and of the treated water every day. They determine the calcium and magnesium content of the natural water, as well as the amount of alkaline hydrate and carbonate in the purified water. The amount of reagent to be added to the natural water is determined from its analysis. In the cases of supplies where the quality of the water varies greatly, the installations are supplemented by large extra tanks or reservoirs where the natural water remains two or three days; this gives the laboratories time to decide on its treatment. The amount of reagent to be used is sent every day from the laboratories to the water-purifying stations and the chemists ascertain, by frequent rounds, that the work is properly carried out. The object of all these precautions is to avoid two risks:

1° Incomplete purification which would give scale-producing water, which would

also have corrosive properties if it contained, as it may, large quantities of magnesium chloride.

2° Purification effected with excess of reagents particularly soda, with the chief disadvantage of priming.

2. *Saving resulting from the use of purified water.* — All the railways state that they are satisfied with the results of the purification of the water, but none can give definite figures as to the saving effected. The Bône-Guelma Company alone gives some information on this subject :

1° As regards fuel consumption, comparisons were made between two similar narrow-gauge locomotives, articulated compounds of the Mallet type, with eight wheels, weighing 30 tons and with a working pressure of 12 kilograms per square centimetre (170 lb. per square inch). When purified water only was used, the coal consumption was 0·0718 kilogram per ton-kilometre (0·2588 lb. per English ton-mile), while the locomotive fed exclusively with natural water required 0·0746 kilogram per ton-kilometre (0·2689 lb. per English ton-mile), i. e. about 4 per cent more;

2° Boilers fed with purified water run more than twice as far, before they require washing, than the others, namely 1,400 to 1,600 kilometres instead of 600 to 700 kilometres (870 to 1,000 miles instead of 370 to 430 miles); the tubes also have more than twice the life; the cost of maintenance of the boilers is largely reduced.

3. *Treatment of water containing salts of calcium and magnesium. Precautions taken against priming.* — The French Northern Railway has found it necessary in practice not to remove in the purification all the calcium sulphate, but to leave from 0·120 to 0·150 gram per litre (8·4 to 10·5 grains per English gallon) in, so as not to introduce into the boilers a quantity of alkaline salt giving rise to violent ebullition and to priming.

On the Bône-Guelma Railway, the water contains much calcium and magnesium sulphate and chloride. Consequently, large quantities of sodium carbonate have to be used; in 1907, on the average, 0·400 kilogram were used per cubic metre (0·0250 lb. per cubic foot) of water treated, on the whole system; the water at Oued Damous often requires more than 1 kilogram per cubic metre (0·0624 lb. per cubic foot). In order to avoid priming, the chemists do not use quite enough sodium carbonate, and remain satisfied with water which is not quite soft. On the other hand, an excess of lime is used in order to remove the magnesium, and reduce the corrosive power of the water.

4. *Use of barium salts.* — No railway uses barium salts for water-purifying purposes.

5. *Quantity of sodium salts producing priming.* — The quantity of sodium salts

present in the water of boilers when priming commences has nowhere been determined.

6. *Disincrustants.* — Several railways make a general use of disincrustants placed direct into the boilers or into the tenders in a liquid form.

The French Eastern Railway uses barium aluminate; the Orleans Railway and the Bône-Guelma Railway an extract of campeachy and quebracho mixed with sodium carbonate; the French Western an extract of quebracho mixed with sodium carbonate; the Midi an extract of quebracho without alkali; the State Railway either barium aluminate or extract of campeachy mixed with sodium carbonate; the Andalusian Railway barium aluminate; the Algerian State Railway a boiler fluid known as " sélénifuge ".

Other railways are using disincrustants only to a small extent or as an experiment. The French Northern and the French State have recently been trying the " Williams " disincrustant, which consists of tannin and barium chloride; the Paris-Lyons-Mediterranean uses barium aluminate, at some places where the quality of the water is not satisfactory; the Italian State Railway, in the case of boilers fed with strongly-incrusting water, contents itself with introducing into the boiler, after it is washed out, from 2 to 3 kilograms (4·4 to 6·6 lb.) of Solway sodium carbonate, according to its capacity; the Belgium State Railway has tried several disincrustants, such as barium aluminate, the Van Baerle disincrustant which consits chiefly of sodium silicate and carbonate, etc., without definitely adopting any one of them.

As regards the effect of disincrustants, it may be stated in a general way, that they render the scale less adherent and softer. Consequently, the latter can be removed more easily from the accessible places when the boiler is washed out. In the case of the less-accessible places, such as the nest of tubes, only a slight reduction in the deposit of scale is observed.

7. *Does the use of disincrustants give rise to leakage of the tubes or stays?* — The general answer is : No. Some railways using bariuma luminate, however, observe that when this substance was first used in boilers in which there already was scale, leaks started; this was prevented by reducing the amount of salt used, so as to remove the scale more slowly.

The normal use of disincrustants has, on the contrary, the chief result that the leakage of the tubes is reduced.

8. *Position of the defects of the boiler.* — Cracks are formed chiefly at the upper bends of the fire-box tube-plate and at the sides, from the rivet holes up to the edge of the joints of the tube-plate, in the interspaces between the tubes and in the bends of the front plate of the fire-box below the barrel.

Pitting is produced in the lower part of the barrel and sometimes in its sides, below the line of water-level. When it becomes more considerable and extends, it

gives rise to a general corrosion of the surface, which is found more especially in the lower part of the barrel, and which makes it necessary, after a considerable time however, to put in some new half-rings.

Grooving occurs in parts subject to bending in alternate directions, particularly at the bends of the front plate of the fire-box, along the frame and along the joints of the rings of the barrel. It also occurs in the bends of the smokebox tube-plate, particularly at the lower part outside, but this grooving is then due to the cinders.

9. *Statistics of defects.* — Some railways only take note of damaged plates and take sketches of them; some others only do so in exceptionally interesting cases. On the Italian State Railway, notes are made of the defects, in the record books of the locomotives; sometimes rubbings or squeezes are taken of the more important or characteristic corrosions; sometimes also photographs of damaged plates are taken, for examination.

This recording of the defects which can be observed not only during general overhauls, but also when the tubes are being taken out, must however be considered of very great importance, for on the one hand, it makes it possible to observe the start and the development of the boiler defects, and on the other hand, it supplies a means of appreciating the influence and the effectiveness of any modifications in the construction.

10. *Modification in the construction of boilers in order to reduce defects.* — The principal modifications tried up to the present are given below :

French Eastern Railway. — In order to avoid cracks in the bends of the front plates of the fire-boxes, these have an internal lining strengthening the plate at the critical places, which are the gusset stays connecting it with the barrel. The breadth of the water-spaces is at least 68 millimetres ($2\ ^{11}/_{16}$ inches). The feed water is delivered forwards, nearly at the height of the centre line of the boiler.

French Northern Railway. — The breadth of the water-spaces has been increased as much as possible; it is at least 76 millimetres (3 inches) at the sides and 95 millimetres ($3\ ^{3}/_{4}$ inches) in front and at the back. The feed water is delivered either near the middle and at the height of the centre line of the boiler, or above the tubes at a distance of 1 to 2 metres (3 ft. $3\ ^{3}/_{8}$ in to 6 ft. $6\ ^{3}/_{4}$ in.) from the tube-plate. In a recent lot of locomotives, the feed water is sent into the steam.

Midi Railway. — The feed water is conducted through an inner tube which starts from the back face and terminates in front of the tube-plate, 0·900 to 2·050 metres (3 feet to 6 ft. 9 in.) from it; this company thinks that the introduction of water of low temperature so near the tube-plate is related to the defects which occur at the tubes and the stays of the fire-box; that is why trials are being made of a new system in which the water is delivered quite towards the front into a tank placed above the level of the water.

Paris-Lyons-Mediterranean Railway. — In order to prevent, as much as possible, the formation of cracks in the bends of the front and back plate of the fire-box, the radius of curvature has been increased from 64 to 100 millimetres (2 1/2 to 4 inches) in the more recent locomotives. This railway has also, as an experiment, on thirty locomotives, strengthened the parts where the cracks more generally occurred by applying pressed plates, exactly fitting the shape of the bends. Moreover, as boilers come in to be repaired, all in which the front plate of the fire-box has a projection at its upper part, are fitted with a conical ring to enable that projection to be done away with. The minimum breadth of the water-spaces is 60 millimetres (2 3/8 inches). In the older boilers the feed water is delivered near the back of the barrel, in the newer ones near the front.

Italian State Railway. — The use of Gölsdorf antifouling apparatus is being tried for the delivery of the feed water in order to reduce the bad effect of the direct delivery of cold water. The same railway is also investigating the application of a feed-water heater and of a third injector of reduced size in order to make a continuous feed possible.

11. *Washing out the boilers.* — Most of the answers received are interesting. We will give them in detail.

French Eastern Railway. — The boilers are washed out with warm water, having a temperature of 35 to 40° C. (95 to 104° Fahr.) either by means of Bohler injectors or by means of Thirion pumps carried on a lorry, with a heater, steam being taken from any locomotive having enough pressure. The rule is, not to wash out the boilers after a given distance has been run, but after every ten days on the average, no matter what the quality of the water may be. The time allowed for the cooling of the boiler depends on how long the locomotive is going to stand still and on the hour it arrives at the sheds, as daylight is wanted for the washing out; as a rule the boilers, particularly those of the larger locomotives, are allowed to cool for twelve hours, and more if possible. A jet of water is used, with sufficient pressure to wash the accessible surfaces well, say with a pressure of 3 to 5 kilograms per square centimetre (43 to 71 lb. per square inch).

French Northen Railway. — Cold water is generally used for washing. On the average, the distance run between two washings is 1,500 kilometres (930 miles) no matter what the quality of the feed water may be. The time allowed for cooling varies very much at the different sheds; it varies between three and twelve hours. The pressure of the water used for washing also varies considerably; between 0·5 and 8 kilograms per square centimetre (between 7 and 114 lb. per square inch).

Hot water is only used for washing at a few sheds, where it is carried out either by means of a fixed injector, or by means of locomotive injectors to which a special connexion is fixed.

An electrically-operated pump is at present being tried.

Midi Railway. — Cold water is generally used for washing. The distance run between successive washings varies with the nature of the service and the quality of the water; it is

about 1,000 kilometres (620 miles, in the case of goods locomotives and about 2,000 kilometres (1,240 miles) in that of passenger locomotives. The time allowed for cooling the boilers is a rule, and as far as possible, twenty-four hours. The pressure of water used depends on the height of the tanks; it is from 1 to 2 kilograms per square centimetre 14 to 28 lb. per square inch).

At Séverac-le-Château station, trials are being made with hot water supplied by means of a Koerting injector carried on a small truck. This apparatus receives the water under pressure of its head, and takes steam from a locomotive in working order by means of a special valve fixed in the dome. The ordinary jet is used for washing. The jet of water, which has a temperature of about 50° C. (122° Fahr.), is very powerful and washes excellently.

Paris-Lyons-Mediterranean Railway. — As a general rule, cold water is used for washing; hot water is used at a few sheds only.

The maximum distance run between two successive washings is given by the equation :

$$n = \frac{35.000}{c\alpha}$$

where n = the distance, in kilometres, between two successive washings, which must not be exceeded;

c = the weight, in kilograms, of fuel comsumed per kilometre;

α = the weight, in grams, of solid residue left when 1 kilogram of water is evaporated.

These distances are increased by 30 to 50 per cent in the case of locomotives with large fire-boxes.

When cold water is used for washing, the locomotive is emptied about five hours after it has arrived at the sheds and washed after a period of not less than twelve hours.

The pressure of the water varies between 1 and 2 kilograms per square centimetre (between 14 and 28 lb. per square inch).

Hot water is used for washing at six sheds only. At each of these sheds, there is a locomotive specially equipped for this purpose, which is run alongside the one that is to be washed. One of the injectors of this locomotive drives the hot water into a rubber hose fixed to the delivery nozzle and fitted at the other end to give a jet for washing. A pressure of 4 to 5 kilograms per square centimetre (57 to 71 lb. per square inch) is kept up in this special locomotive, and this is enough to give a jet of hot water having a temperature of 50 to 60° C. (122 to 140° Fahr.). At these sheds, it is the rule that hot water is used for washing all the boilers of the locomotives which stop at the sheds for less than seventeen hours, and which consequently cannot cool sufficiently to enable cold water to be used for the washing.

Bône-Guelma Railway. — Cold water at a pressure of 2·500 kilograms per square centimetre (35·55 lb. per square inch) is used for washing, after a distance of 1,200 to 1,400 kilometres (750 to 870 miles) has been run. Now that the more impure water is purified, the quality of the water is no longer taken into consideration in fixing the distance. The time allowed for cooling is twenty-four hours

Italian State Railway. — Hot water is generally used, after runs of from 1,200 to 2,000 kilometres (750 to 1,240 miles), according to the quality of the water. The time allowed for cooling is four hours if hot water is used for the washing, and ten hours if cold water is used. The pressure of the water varies between 2 and 4 kilograms per square centimetre (between 28 and 56 lb. per square inch). The injector and the water of another tender and locomotive are often used.

Belgian State Railway. — Cold water is generally used for the washing. The distance run between successive washings varies according to the nature of the service. The average interval between successive washings is eight days. At least twelve hours must elapse, in the case of locomotives with arch and covered with lagging, between the time of drawing the fires and the time of washing with cold water. The pressure of the water must be as nearly as possible adjacent to 1·5 atmospheres. Several systems of hot-water washing are being tried; as yet none has been definitely adopted.

Andalusian Railway. — Hot water has now been exclusively used for the washing, for the last five years. The average distance run between two successive washings is 850 kilometres (530 miles) in the case of passenger locomotives, and 700 kilometres (430 miles) in that of goods locomotives. The injector of any locomotive available is used, in which a pressure of 5 to 6 kilograms per square centimetre (71 to 85 lb. per square inch) is kept up. The washing takes forty to fifty minutes. In case of necessity, as soon as the pressure in the locomotive which is to be washed has dropped, it can be emptied, washed, and refilled, always using hot water. If this method is adopted, the total time the locomotive has to be at rest does not exceed five hours.

12. *Blowing-off Boilers.* — Only a few railways proceed to methodical removal, that is to say, to blowing off a portion of the water under pressure in order to remove the deposit and to check priming.

On the Bône-Guelma Railway, on the Algerian State Railway and on the Italian State Railway, such removal is effected by means of the blow-off cock, after runs of 400 to 500 kilometres (250 to 300 miles), or even after each individual run.

The Andalusian Railway has now for some time been applying such a system very thoroughly. Each boiler has three stop-spindle valves operated direct from the foot-plate by means of hand-wheels. One of these valves is at the bottom of the front face of the fire-box, at the spot where the blow-off cock is generally placed; the other two are on the one side and the other of the smoke-box tube-plate, a little lower than the horizontal plane passing through the centre line, each at the end of a smoke tube, the other end of which is several centimetres away from the fire-box tube-plate, the corresponding hole in which is of course plugged. These two valves are intended to remove the deposits which tend to form in the neighbourhood of the fire-box tube-plate.

13. *Analysis of specially-corrosive waters.* — Specially-corrosive waters are to be found in Algiers only. The Bône-Guelma Railway supplies very interesting

information on this point. The water supplies contain no free acid except carbonic acid, but they contain much magnesia and much chlorine, and hence are very corrosive and form much scale. The following table shows in grams per litre the variations of the different impurities :

	Grams per litre.	(Grains per English gallon).
Ca O	from 0·59 to 0·21	(41 to 15)
Mg O	— 0·04 to 0·31	(3 to 22)
Ca C O_3	— 0·10 to 0·26	(7 to 18)
S O_3	— 0·11 to 1·02	(8 to 72)
Cl	— 0·05 to 1·64	(4 to 115)
Mg Cl_2	— 0 to 0·75	(0 to 53)
Na Cl	— 0 to 1·78	(0 to 125)
Na_2 S O_4	— 0 to 0·56	(0 to 39)
Ca S O_4	— 0 to 0·75	(0 to 53)
Total solids dried at 150°	— 1·14 to 3·21	(80 to 225)

Now that the purification is effected and although but little magnesia is left in the water, less than 0·015 gram per litre (1 grain per English gallon) on the average, the corrosion of the barrel and of the stays seems of greater importance than before the purification.

14. *Coating intended to protect the plates.* — As a general rule, no coating intended to prevent the corrosion of the plates is used.

The French Eastern Railway paints the inside of the boilers with a mixture of 25 per cent of blacklead and 75 per cent of mineral-varnish.

On the Italian State Railway, trials have recently been made with a coating of cement, applied with a brush. This coating seems to adhere sufficiently and lasts several months.

15. *Use of zinc plates.* — No railway uses the zinc method of disincrustation. The French Northern and the Paris-Lyons-Mediterranean formerly made trials which were not followed up, as the results were unfavourable.

The Italian State Railway is making a trial of another character, which presents certain interest and has given good results up till now. Copper sheet 2 millimetres ($^3/_{32}$ inch) thick is applied to the lower part of the inner surface of the barrel, over about one third the circumference and over the whole length. The application of copper sheet to the lower part of the fire-box plate which is in contact with the foundation ring is also being tried.

16. *Stays.* — All the more important railways use only manganese bronze for the upper parts of the fire-boxes; plain copper continues, as a rule, to be preferred for the lower stays. But the height at which the change from manganese bronze to

copper is effected, varies considerably. Sometimes manganese bronze is only used for the four or five upper rows, but frequently it is used down to the level of the arch or even a little lower.

The manganese bronze is an alloy of copper and manganese, containing about 5 per cent of the latter metal. Its ultimate tensile strength (33 kilograms per square millimetre [46,935 lb. per square inch]) and its elongation (33 per cent) become reduced less rapidly at high temperatures than those of copper.

Fractures of manganese bronze stays are much rarer than fractures of copper; but the fire attacks the heads a little more quickly; this does not cause too much inconvenience, as the thread holds well in the plates. Fractures of copper stays occur frequently enough in the large, long, narrow fire-boxes of modern locomotives. They most frequently happen close to the place where the stay enters the fire-box plate; this tends to show that the fracture is due to the alternate bending the stay is subjected to, near the point where it is fixed to the outer shell, by the expansion of the copper plate.

As regards the positions in the box, in which fractures occur most frequently, opinions differ considerably. Some railways have observed that fractures are more frequent in the upper rows, in the corners and at the top of the arch; other railways find that the fractures occur in the lower part of the fire-box, particularly below the arch.

In order to detect fractures, all the railways are satisfied with drilling a hole 3 to 6 millimetres ($^1/_8$ to $^1/_4$ inch) in diameter into the centre of the stay. In France, the hole extends right through the stay, but the exterior end of the hole is plugged. On the Italian and Belgian railways, the holes are only drilled in to a depth of 40 millimetres ($1\ ^9/_{16}$ inch) at each end.

No railway uses flexible stays.

17. *Lining the fire-box with fire-bricks.* — This system of protecting the fire-box plates has not been tried.

CONCLUSIONS.

The principal damage to boilers due to :

Cracks in the fire-box tube-plate, in the bends and in between the tubes;

The wear of the lower part of the fire-box plates around the heads of the stays;

Cracks and grooves in the front and back plates of the fire-box and in the tube-plate of the smoke-box;

Pitting and general surface corrosion in the lower part of the barrel and along the seams.

Water of bad quality accelerates the production of these defects.

Consequently, the purification of feed water of medium quality is to be recommended; it becomes indispensable when the water contains a large proportion of alkaline earth salts. But in order to prevent priming, the purified water should contain as little sodium salts as possible.

The use of disincrustants is also to be recommended, although they do not do away with the formation of scale and are only a palliative.

Washing out the boilers with hot water and blowing off under pressure help to keep the boilers in good condition.

APPENDIX.

Detailed list of questions relating to question VI, littera A and C.

Littera A.

1. What type of boiler do you use? Belpaire or round-topped? Please forward drawings of your latest standard types.

2. If you use round-topped boilers, do you use roof-bar or radial stays on the fire-box crown-sheets? Kindly state what special advantages you find from each type.

3. Have you any locomotives fitted with cylindrical fire-boxes? If you use this type, please submit drawings and describe the advantages or disadvantages derived from the use of this design.

4. Are any of your boilers fitted with combustion chambers? If so, please supply drawings and state what results have been obtained with this method of construction.

5. Have you constructed any boilers with fire-boxes of any other material than copper? If so, what have been the results compared with copper fire-boxes of the same design.

6. What shape and size of firehole do you find the most suitable? Do you employ any special door or other special means of air-admission? Do you use a ring joint or dished joint between the inner fire-box plate and back plate? If the former, how is it fastened?

7. What is the proportion between the total grate area, air-space in the firegrate, and total tube area? Are any of your boilers fitted with rocking or drop grates?

8. In very long boilers, do you employ any form of intermediate support for the barrel of the boiler?

9. Which type of front tube-plate do you fit your boilers with, viz., drum-head, or plate with extension fitted to the cylinder casing?

10. What material are your tubes constructed of? Give reasons for the adoption of the metal or alloy you employ.

11. What are the dimensions of tubes used in your standard type of boiler, including thickness at each end?

12. What is the method employed in fixing tubes in your boilers? Kindly give a description, with sketches, of any special machines or device employed for this purpose. Are the tubes expanded in any particular order?

13. Have you had any experience with Serve tubes? If so, please supply particulars.

14. Are you troubled with

a) Pitting of steel or iron tubes?

o) Excessive wear or fracture of copper or brass tubes just inside the copper tube-plate?

What steps do you take to counteract these defects? Have you tried galvanized steel or iron tubes, and, if so, with what results?

15. Do you employ ferrules in tubes? If so, with what object in view, *e. g.* :

a) Keeping the tube tight?

b) Protecting the end of the tube from the action of the fire?

What taper and thickness of ferrule do you use? Do you bead the ends of your tubes and, if so, with what results? If this has been tried and given up, what cause led to its being discontinued?

15bis. To what causes do you attribute the leakage of the tubes at the fire-box? What means do you adopt to counteract it?

16. How are your tubes arranged in the tube-plate, *i*, *e.*, in vertical or horizontal rows? State the reason for your practice. What space is allowed between the tubes?

17. Do you employ pressures above 180 lb. per square inch and, if so, have any special means had to be taken to cope with these pressures, especially in the keeping of the tubes tight and in maintaining the fire-box tube-plate in good condition?

18. Has it been found that any special spacing of the tubes or stays has led to a decrease in the trouble experienced from cracked corners of the tube-plate?

Have you tried cold hammering of the copper tube-plate in order to harden it and, if so, with what results?

18bis. What methods do you adopt for repairing the different defects affecting the tube-plates?

19. Do you use an extended smokebox? If so, what advantages are derived from it.

20. In your latest standard types of boilers, do you fit a steam-dome and, if not, what device is in use to obtain dry steam?

21. What material is used for lagging your boilers? Are the boilers lagged inside the cabs? If you have made any tests to ascertain the relative efficiency of different lagging materials, kindly give particulars and results.

22. Do you employ any system of thermal storage and, if so, what advantage do you derive from it?

LITTERA *C.*

1. What process, or processes, do you use for softening water? Give particulars of the chemical treatment, stating what chemicals are used; and, without describing well-known methods, give details of any special methods or apparatus you employ, or any special details connected with the working of the ordinary methods of treatment which you have found advantageous. What precautions are observed to ensure the treatment being properly carried out?

*

2. State whether you are satisfied with the results obtained and, if possible, give figures shewing the saving effect in :

1° Fuel ;
2° Cost of cleaning and retubing boilers ;
3° Cost of repairs to and life of boilers ;
4° Cost of water (*i. e.* by being able to use water which can be obtained cheaply, instead of having to purchase expensive water of better quality.)

3. How do you deal with waters of which the hardness is mainly or largely due to calcium and magnesium sulphates, chlorides or nitrates? Do you soften such waters, and if so, what precautions do you take to prevent priming of the boilers caused by sodium salts introduced in softening?

4. Have you used barium hydroxide, barium carbonate, or barium aluminate in softening water containing sulphates. If so, please give particulars, results and cost of treatment, and state whether you find it pays.

5. Have you made any attempt to ascertain the quantity of sodium salts present in the water of locomotive boilers when priming commences? If so, please give particulars and results of these experiments.

6. Do you use, or have you used, disincrustants placed directly in the boilers, instead of treating the water before use? If so, state the nature of the materials used, and the results obtained.

7. In connection with water softening or the use of disincrustants, have you been troubled with excessive leakage of boiler tubes or stays? If so, kindly give particulars, stating what you conceive to be the cause of the leakage and whether any and, if so, what means you have found effectual in preventing or lessening this leakage.

8. On what portions of the interior of the boiler do the following defects occur :

1° Cracks ;
2° Pitting ;
3° Growing ;
4° General surface corrosion.

9. When the boilers undergo heavy repairs, are any notes made on the repair sheets as to the defects mentioned in question 8? Are sketches made on the sheets illustrating the actual nature, position and dimensions of these defects? If so, kindly supply some of these sheets chosen from amongst those giving the most characteristic defects.

10. What are the methods employed in the construction of boilers to prevent any of the defects referred to in questions 8 and 9? Have modifications been carried out in the design of the boilers with this end in view? What is the breadth of the water-spaces in the fire-box? Where is the feed-water delivered, and in what manner?

11. Are the boilers washed out with cold or hot water? What are the mean mileages between two washings-out? In fixing these mileages, is account taken of the quality of the water? What is the time allowed for cooling down before the boiler is washed out with cold

water? What pressure of water is used for washing-out? If any system of washing-out with hot water is employed, kindly describe this fully.

12. Is blowing off a portion of the water under pressure resorted to in order to prevent the formation of deposit and to check priming? If this practice is carried out, at what time and after what intervals is it done? What means are adopted to remove the water? Shew by sketches the position of the blow-off cock and its design.

13. If you have any waters which are specially corrosive to boilers, but which by analysis are not found to contain free mineral acid, please give analyses stated in parts per 100,000 shewing if possible) the amounts of

Lime (Ca O).
Magnesia (Mg O).
Soda (Na_2 O).
Alkalinity (as Ca CO_3).
Sulphuric anhydride (S O_3).
Nitric anhydride (N_2 O_5).
Chlorine (Cl).
Carbon Dioxide (CO_2), free
Total Solid Matter at 130° C.

14. Have you tried to prevent corrosion by coating the insides of boilers with Portland cement or any kind of paint, or by treating the water with a definite excess of lime or other chemical to neutralize carbonic or other acid, or by ntroducing chemicals or other substances into the boilers? If so, please give full particulars and results.

15. Do you use zinc plates in your boilers? If so, explain, with sketches, the method of application and the results as regards

1° Prevention of incrustation;
2° Prevention of pitting and corrosion.

16. What metal or alloy is used or has been tried for fire-box stays; if any metal other than copper or iron, give composition. What advantages have been found to result from the use of these other metals or alloys? Is any trouble experienced with stays breaking; if so, please state where these fractures occur and indicate :

1° The position in the stay itself;
3° The position of the stays in the box.

Are any special means adopted to detect fractures? Is any type of flexible stay used? Are you troubled with stay heads burning away and dropping off in the fire-box? If so, what means have been adopted or tried to prevent this, and with what result?

17. Have you tried lining the fire-box or any part of it with firebricks or fireclay slabs to protect the stays from the action of the fire and to promote better circulation of the water in the fire-box; if so, give results, and state the nature and composition of fire-resisting material used.

[621 .133.3, 621 .134.3 & 621 .133.7]

REPORT N° 2

(Australasia, Great Britain, India and South Africa)

By H. FOWLER,
LOCOMOTIVE WORKS MANAGER, MIDLAND RAILWAY,

and L. ARCHBUTT,
CHEMIST, MIDLAND RAILWAY.

The following is a list of the Administrations from whom replies have been received :

Australasia.

1. — New South Wales Government Railways.
2. — Tasmanian Government Railways.
3. — Western Australian Government Railways.

Great Britain.

4. — Caledonian Railway.
5. — Furness Railway.
6. — Great Central Railway.
7. — Great Eastern Railway.
8. — Great Western Railway.
9. — Hull & Barnsley Railway.
10. — Lancashire & Yorkshire Railway.
11. — London & North Western Railway.
12. — London Tilbury & Southend Railway.
13. — Midland Railway.
14. — North Eastern Railway.
15. — South Eastern & Chatham Railway.
16. — Taff Vale Railway.

*

India.

17. — Eastern Bengal State Railway.
18. — East Indian Railway.
19. — Great Indian Peninsula Railway.
20. — North Western Railway (State Railway of India).
21. — Oudh & Rohilkhand Railway (State Railway of India).
22. — Southern Mahratta Railway.

South Africa.

23. — Cape Government Railways.
24. — Central South African Railways.
25. — Natal Government Railways.

A. — Boilers with smoke tubes; precautions in constructing and maintaining tubes and tube-plates.

1. — *Type of boiler used.*

There is a general tendency towards the adoption of the Belpaire fire-box, both by British & Colonial Administrations, and most of these in their latest designed locomotives are arranging for fire-boxes of this type. The exceptions are the Caledonian, Furness, London & North Western, London Tilbury & Southend, North Eastern, Taff Vale & Cape Government Railways, who use only round-topped boxes, while the Western Australian Government Railways use both types, but have recently been fitting round-topped boilers.

The increased usage of the Belpaire fire-box has been a development of recent years, and undoubtedly points to this design meeting with general favour. One advantage gained by its adoption is that the heavy roof-bars used with round-topped boilers can be dispensed with, as the two flat surfaces on either side of the space over the box are more simply stayed than when one is a flat and the other a curved surface, thus giving a greater flexibility under the variable temperatures met with. The steam and water-space is greater with the Belpaire fire-box. Removing the incrustation and deposit from the fire-box crown is also a much simpler matter and can be more satisfactorily accomplished, the general practice being to fix washout holes on either side of the crown, so arranged that succeeding sections of the water-space can be cleaned, first from the right-hand side, then from the left, and so on (see fig. 1 for position of washout holes).

One of the problems met with in introducing this fire-box was the difficulty of flanging the throat-plate, but this has now been completely solved by the introduction of flanging presses of sufficiently high power, and the throat-plate now forms one of the best standing parts of the boiler. It is the general practice with the

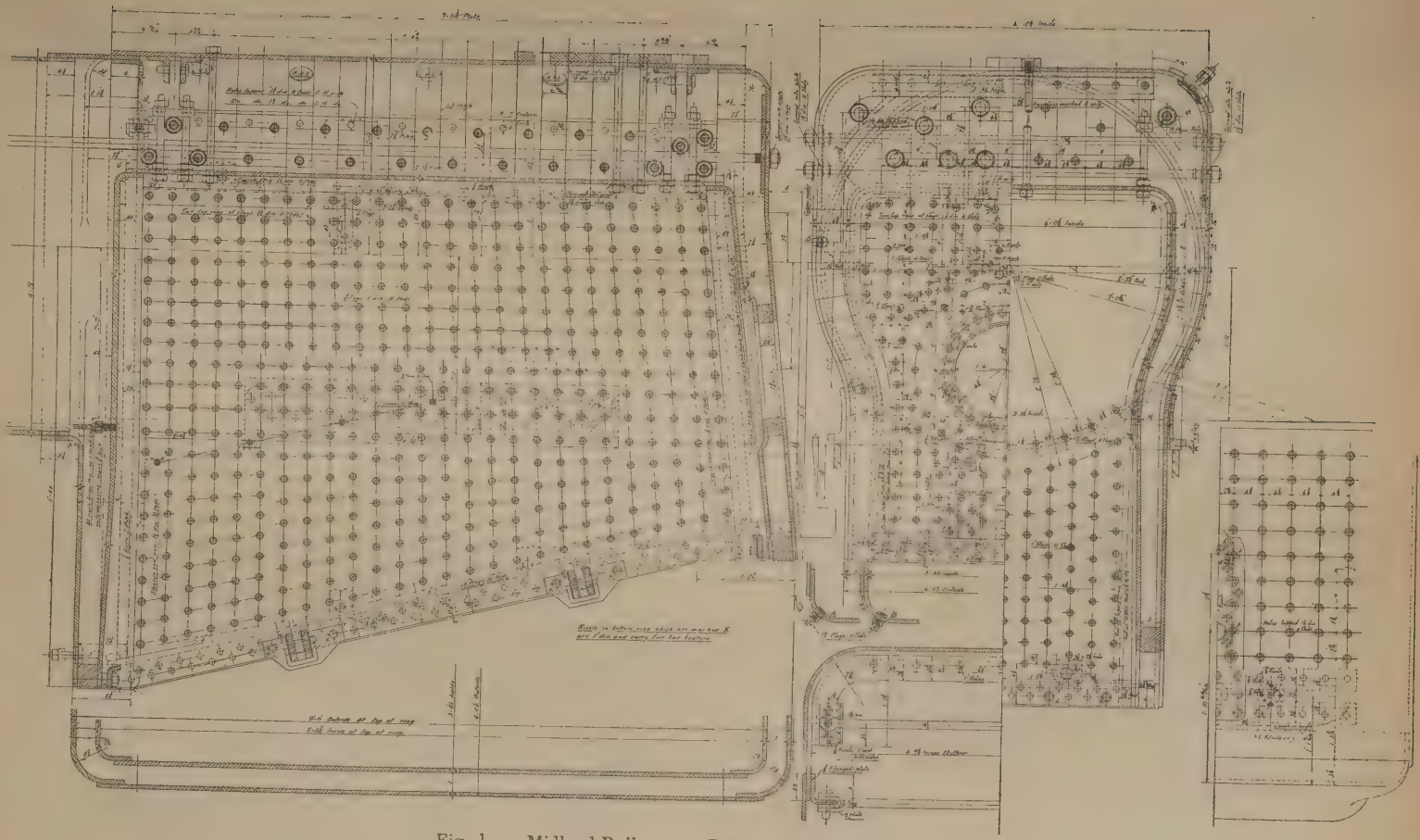
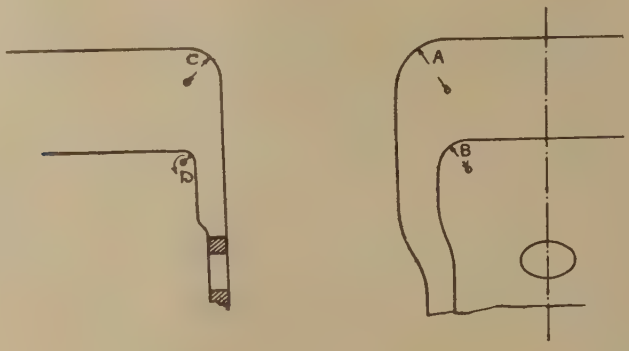


Fig. 1. — Midland Railway. — Belpaire fire-box arrangement.

Belpaire fire-box to use sling stays at the front end (usually two or four rows) and vertical stays for the remainder, but according to Mr. Churchward, the Great Western Railway has recently made a test of this type wherein no sling stays were used, and the results obtained were of such a nature as to make it appear that they were unnecessary, and that vertical stays might be used throughout. If this be the case, the old theory of the necessity of using sling stays to allow for the upward expansion of the fire-box tube-plate, must fall to the ground.

The following list gives the radii of the flanges in the fire-box inner and outer casings as shewn in the sketch :



Radii of Belpaire fire-box plates.

ADMINISTRATIONS.	A	B	C	D	*Remarks.*
	Inches.	Inches.	Inches.	Inches.	
New South Wales Government Railways .	8	4 1/2	3	1 3/4	
Western Australian Government Railways.	8 1/2	...	3	...	
Great Eastern Railway	8 9/16	4 1/2	3	...	
Hull & Barnsley Railway.	10	5 1/2	4	1	
Lancashire & Yorkshire Railway . . .	9	4 1/2	4 1/2	1	
Midland Railway	8 1/2	3 1/2	3 1/4	1 1/4	
South Eastern & Chatham Railway. . .	9 1/2	4 1/4	3	1	
Eastern Bengal State Railway	9	4	5 3/8	1	
Great Indian Peninsula Railway. . . .	9 5/8	4 1/2	5 7/16	1	
Southern Mahratta Railway	8	...	4 1/16	...	
Central South African Railways. . . .	9	6 1/4	3	1	Fire-box over frame.
Natal Government Railways	9	6	3 5/16	1	Ditto.

2. — *Roof-bars or radial stays for round-topped boilers.*

Of the Administrations replying, eleven use roof-bors exclusively, five use radial stays exclusively, while the remainder use both types.

Roof-bars. — These allow for expansion of the fire-box due to heating, at the same time offering resistance to the boiler pressure in the water-space. The Oudh & Rohilkhand Railway find that they also prevent the tube-plate from rising upward and bending the flange, which results from the frequent expanding of the tubes. The Western Australian Government Railways write thus : " Of " 150 locomotives with roof-bars not one had a cracked crown-sheet, while those " with radial stays are always cracking. The sling stays, moreover, accommodate " themselves to the expansion of the box without producing cross-bending " stresses in the material, as is the case with radial stays." The use of roof-bars is stated by some Administrations to decrease the number of broken stays in the fire-box.

The disadvantages accruing from their use are that they are cumbersome and bulky, and thus tend to prevent circulation of the water; also the spaces between them and the fire-box-crown become filled up with deposit which is difficult to remove. The most common form of bar is shewn in figure 2, and it is usually made of cast steel. On one Railway, these bars are built up of mild steel plates (see fig. 3); but this practice is the exception, and an objection raised to this method is that the interspaces between the plates get badly clogged with scale. The Western Australian Government Railways find the solid bars more durable than two plates, the latter failing through corrosion at the junction of the distance ferrules and at the end of the bars where they rest on the box.

Radial stays. — These give a free circulation of the water, and washing of the fire-box crown is rendered much simpler by their use. Not being so bulky as roof-bars, they give a rather greater steam-space.

The Tasmanian Government Railways find that they keep the crown sheet and tube-plate in better shape than roof-bars. The Western Australian Government Railways state that their radial stays give trouble by breaking, either from corrosion about one to three inches above the crown sheet, or from fatigue near the shell plate; also that with radial stays their crown sheets cause considerable trouble through cracking. The South Eastern & Chatham Railway find that with radial stays the roof of the box comes down and the tube-holes crack. When these stays are used, it is the general practice to use sling stays at the fire-box tube-plate end in conjunction with them.

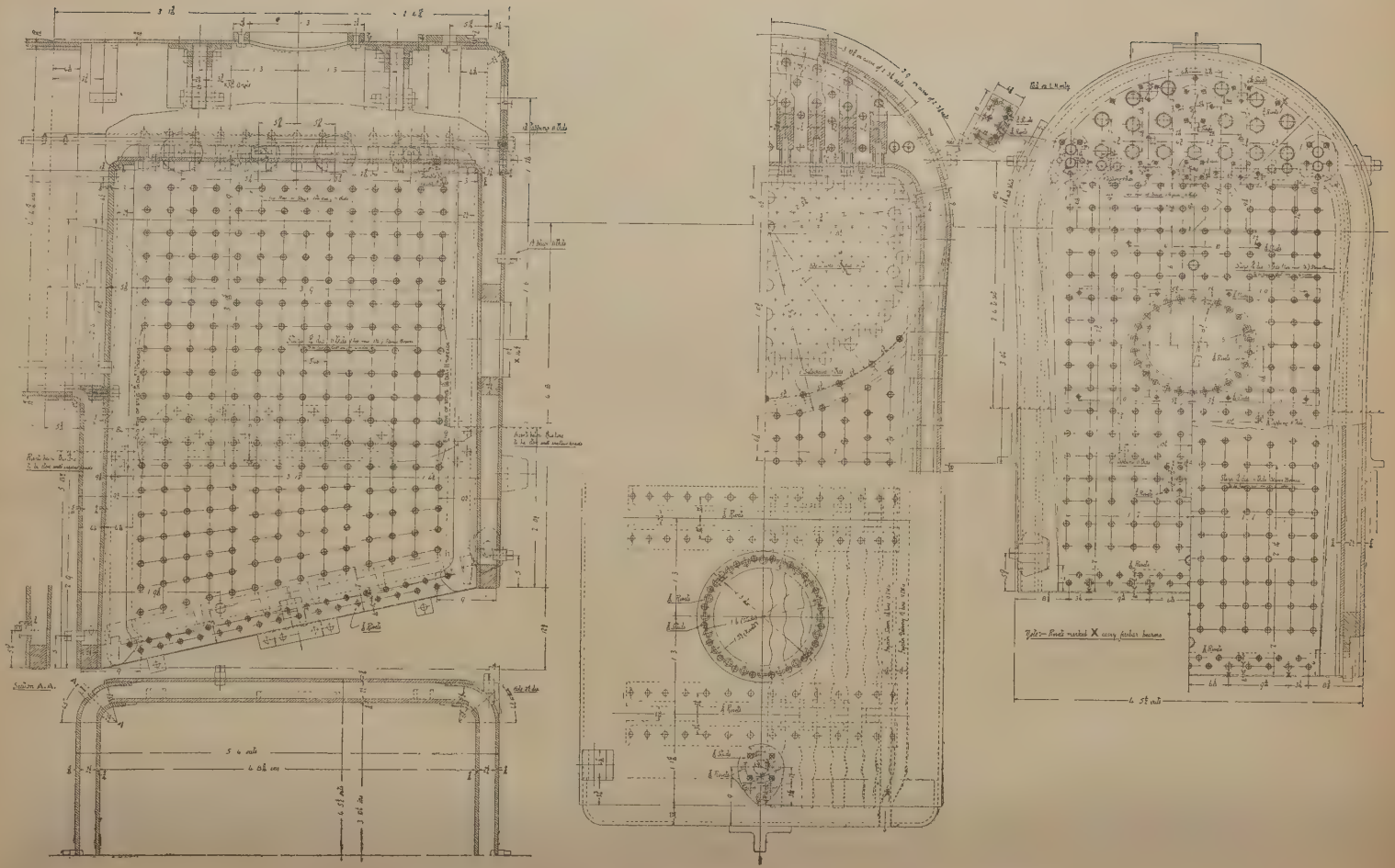


Fig. 2. — Midland Railway. — Fire-box arrangement—N. C. C. with cast steel roof-bars.

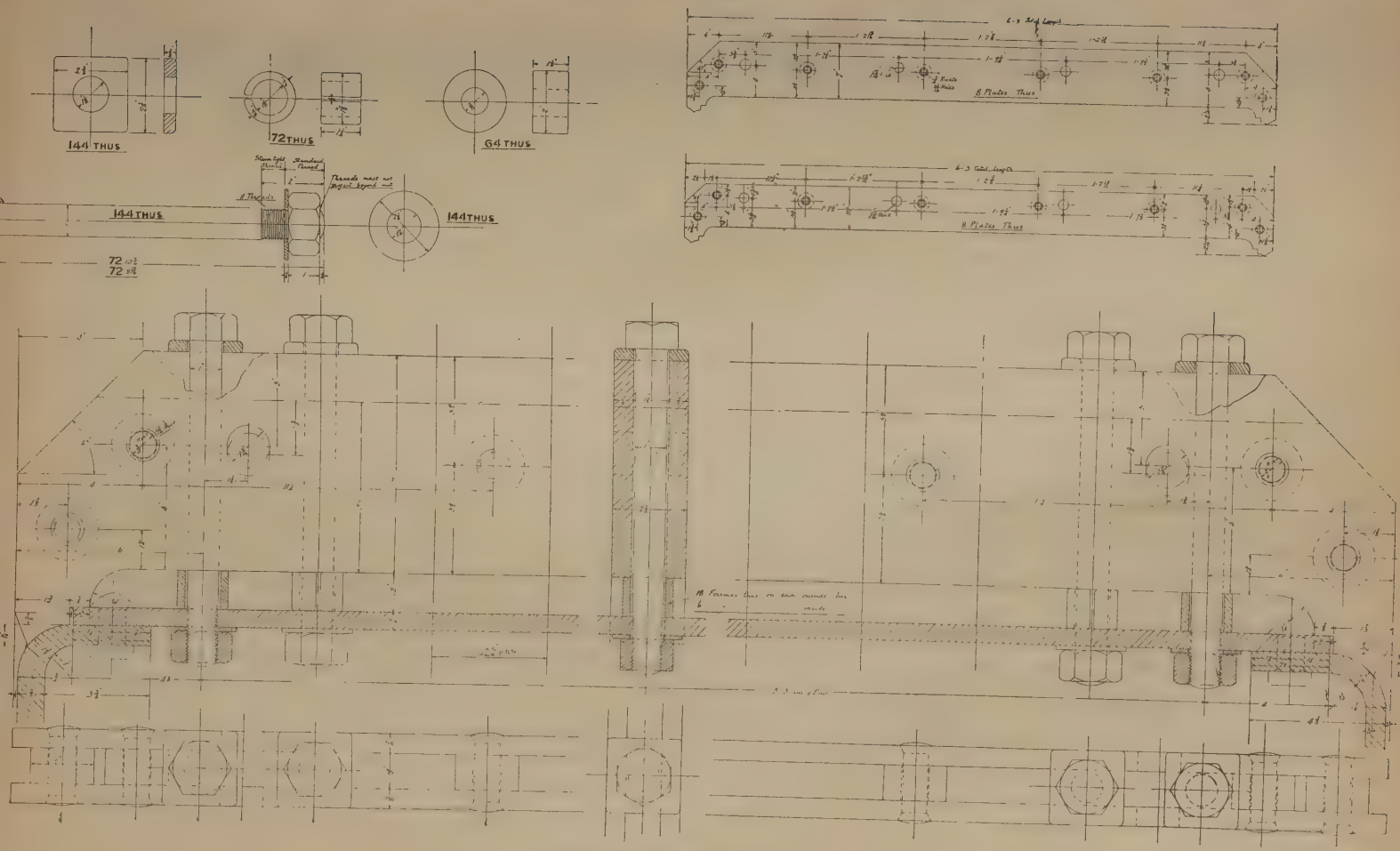


Fig. 3. — Plate roof-bars.

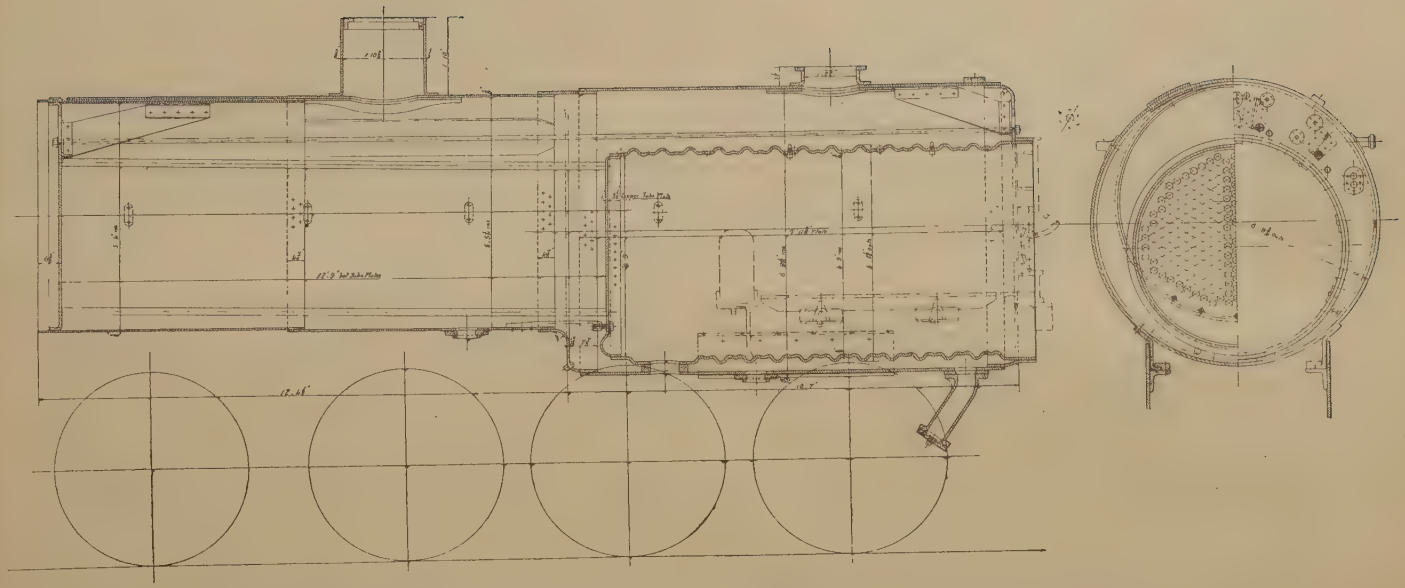


Fig. 4. — Lancashire & Yorkshire Railway. — Arrangement of boiler with corrugated fire-box.

Hydraulic test with warm water	400 lb. per square inch.
Working pressure of boiler	180 — — —

Heating surface :

Tubes.	1,882 square feet.
Fire-box.	125 — —
Total. . .	2,007 square feet.
Grate area	26 — —

3. — *Cylindrical fire-boxes.*

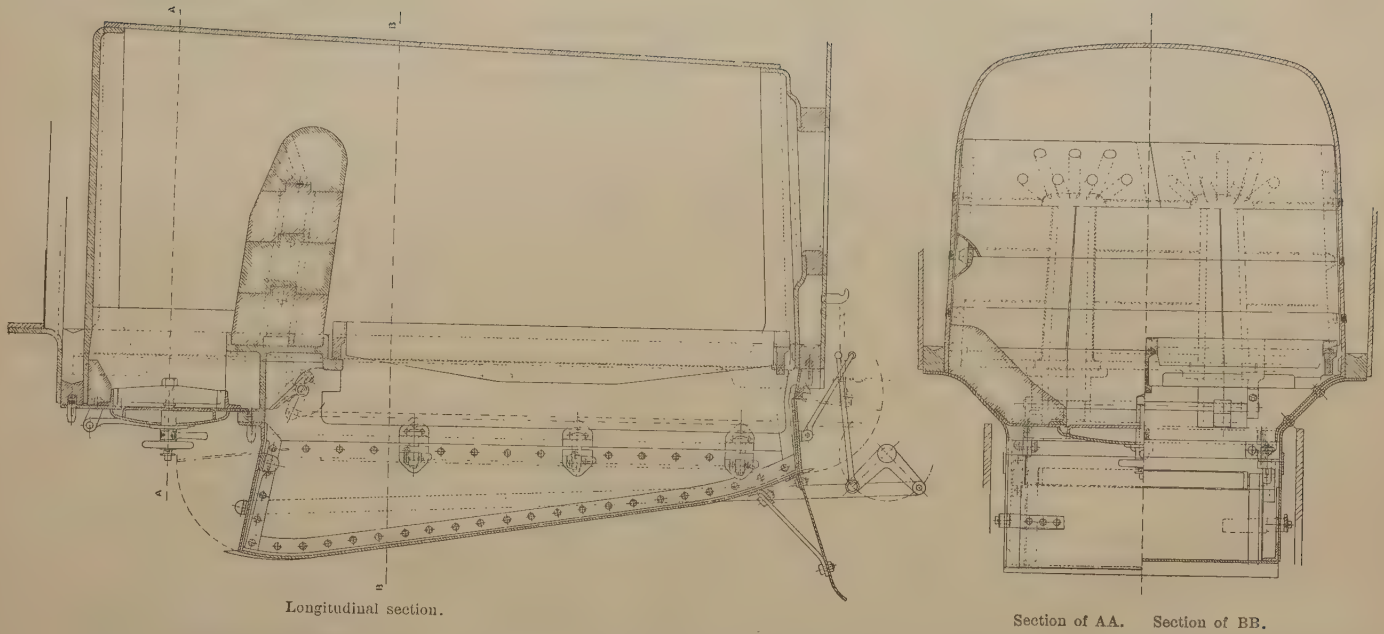
These have been tried experimentally on the Great Western Railway, whilst both the Lancashire & Yorkshire and the London & North Western Railways have a number running. The Lancashire & Yorkshire Railway have twenty-one in service, and the London & North Western Railway twenty-five. The former Railway employs them on eight-wheeled goods engines and uses a corrugated box (fig. 4) whilst the London & North Wertern Railway uses a plain box and has this type fitted on some of its Yard Shunting Engines.

Some considerable trouble was experienced by the Lancashire & Yorkshire Railway through leakage of the tubes in this type of box, but it was found that this took place in those engines which were fitted with steel tube-plates, and two of the engines which were fitted with copper tube-plates gave no such trouble. In consequence of this, all the steel plates have now been replaced by copper.

This type of boiler offers some advantage owing to its simplicity of design and consequent simplicity of repair; a further advantage is that it allows of an even distribution of weight, and the initial cost of engines fitted with it is low. The chief disadvantage lies in the fact that the circulation is bad, and this renders steam-raising a sluggish process, but if this latter feature is not of great importance, cylindrical boilers appear to be capable of doing useful and economical work. They have met with high praise from Mr. R. M. Livesey of the County Donegal Railways, Ireland (*Proc. Inst. Mech. Eng.*, 1906, p. 249), who used engines fitted with this type of fire-box of his own design on short runs with heavy loads and gradients, finding " that the ' circular ' type of boiler steamed much more easily and was " much more economical in coal than the other " a result opposed to the experience of the Lancashire & Yorkshire Railway.

4. — *Combustion chambers.*

Only one of the Administrations replying, *viz.*, the London & North Western Railway, has experimented with a combustion chamber placed between the fire-box and smoke-box tube-plates, but the experience gained has not led them to reproduce this type. A portion of the fire-box itself used as a separate combustion chamber is an arrangement employed by the Western Australian Government, Cape Government and Natal Government Railways The former, as will be seen from the drawing (fig. 5), throw a brick partition across the box, and admit " secondary " air through holes in this. The other two lines bring an ordinary brick-arch backward, and allow the portion between this and the tube-plate to form the combustion chamber, as shewn in figure 6. In these last two cases the fire-boxes are wide and shallow.



Longitudinal section.

Section of AA. Section of BB.

Fig. 5. — Western Australian Government Railways. — Locos' class QA. Combustion chamber, brick arch and damper arrangement.

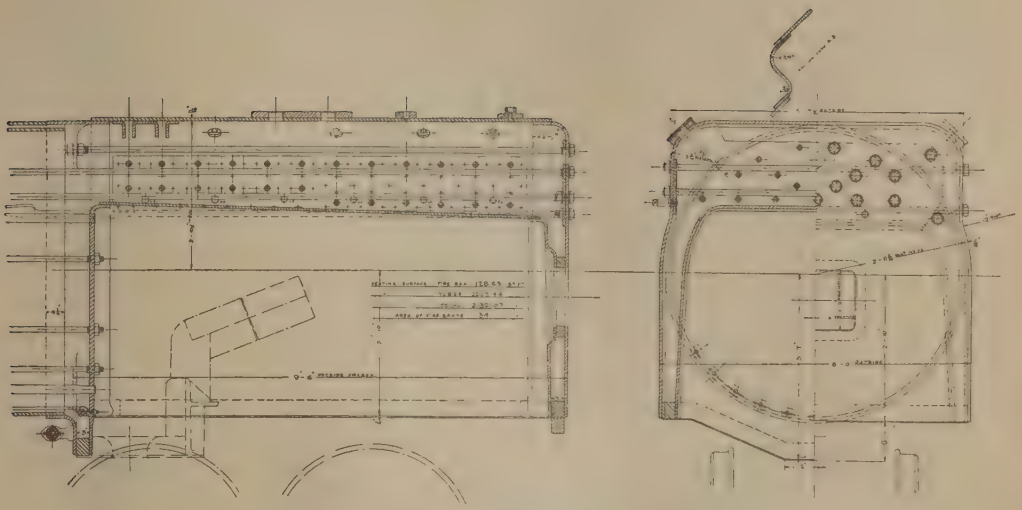


Fig. 6. — Natal Government Railways. — Fire-box.

5. — *Fire-box material.*

Most of the Administrations are using copper for their fire-boxes, eight of them have tried or are trying steel, one has tried steel and " Melloid " [1], and another iron. Of those using steel, the most satisfactory results are reported by the Caledonian Railway who find no perceptible difference between this material and copper, and by the Cape Government Railway who " have some American built " locomotives with steel fire-boxes. The $^1/_2$ inch steel tube-plate stands better " than a $^7/_8$ inch copper plate, the tube holes not being liable to become so distorted " in shape. The steel plate withstands the effects of coal containing a high percen- " tage of sulphur better than the copper plate, but is liable to groove just above the " foundation ring ". Of the others, the Natal Government and Great Central Railways are now trying steel fire-boxes, but they have not been long enough in service to make the results of any value, while the New South Wales Government, Great Eastern, Great Western, London & North Western and Southern Mahratta Railways have discontinued using them, in some cases owing to serious corrosion on the water side, and in others, because of cracking of the plates after very short service. The Great Wertern Railway found that Melloid plates burned away where exposed to the flame, and the two iron fire-boxes used by the North Eastern Railway did not last in service for twelve months. It is interesting to notice that in the report issued by

(1) A copper-tin alloy, containing about 97 p. c. copper, 3 p. c. tin, and a trace of phosphorus.

the Pennsylvania Railroad Company of the tests of eight locomotives at the Louisiana Purchase Exposition at St. Louis in 1904, no increase in economy or capacity could be traced to the copper fire-boxes with which two of these engines were fitted.

6. — *Fire-hole-door particulars.*

It will be seen from table 1 that most of the fire-holes are of circular shape, others being rectangular, square or oval; in this table will also be found the size of the fire-hole. Many of the doors open inwards, being hinged at the top (fig. 7

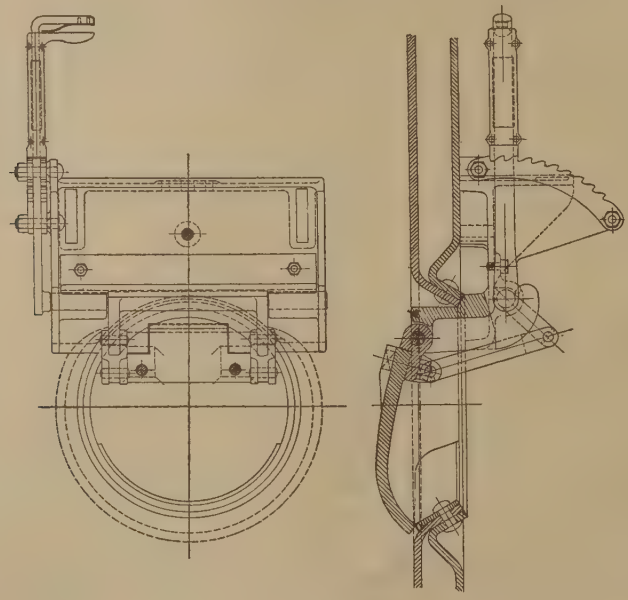


Fig. 7. — London & North Western Railway. — Fire-door.

as for instance those used on the London & North Western and Lancashire & Yorkshire Railways, and the regulation for air-admission is obtained by opening the door by means of a lever working over a quadrant rack. The Western Australian Government Railways employ a circular fire-hole door, hinged at the right-hand side, and having a disc air-regulator in the door; this type is said to give great satisfaction (fig. 8). Instead of this disc regulator, some Administrations using a door of this type have the central portion of the door controlled separately by a

lever working in a notched quadrant. Still another type is the sliding door opening from the centre outwards by a single lever action (fig. 9).

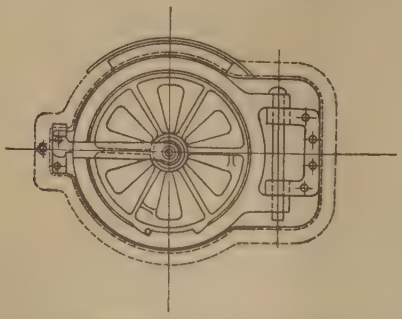


Fig. 8. — Western Australian Government Railways. — Fire-door.

Construction of fire-hole joint between inner fire-box plate and back plate. — The general practice is to use the rivetted ring-joint, but the exceptions to those using this method are the Great Western, Lancashire & Yorkshire, London & North Western, North Eastern and Cape Government Railways, who use the flanged fire-hole-joint. For the cracking and grooving of these two types of joints see section C.

7. — *Proportion between total grate area, air-space in the fire grate and total cross-sectional tube area.*

Table 1, shews the relative values of these areas taken with the grate area as unity. The high value reached on some Railways for the air-space in the grate, is probably accounted for by the use of inferior coal, as in the case of the Indian Railways, where good coal is difficult to obtain. There may be some discrepancy in the figures relating to the cross-sectional area through the tubes as, although this cross-section was intended to be taken through the most restricted area, *viz.*, through the ferrules, this was not explicitly stated in the questions, and it seems probable that some Administrations have taken this section through the tubes, away from the ferrules.

Rocking or drop grates. — The following are the replies received relating to this subject :

New South Wales Government Railways . .	We use very few of these grates.
Western Australian Government Railways.	We use rocking bars, these being necessary when burning the local coal, and 50 per cent are fitted with dump grates.

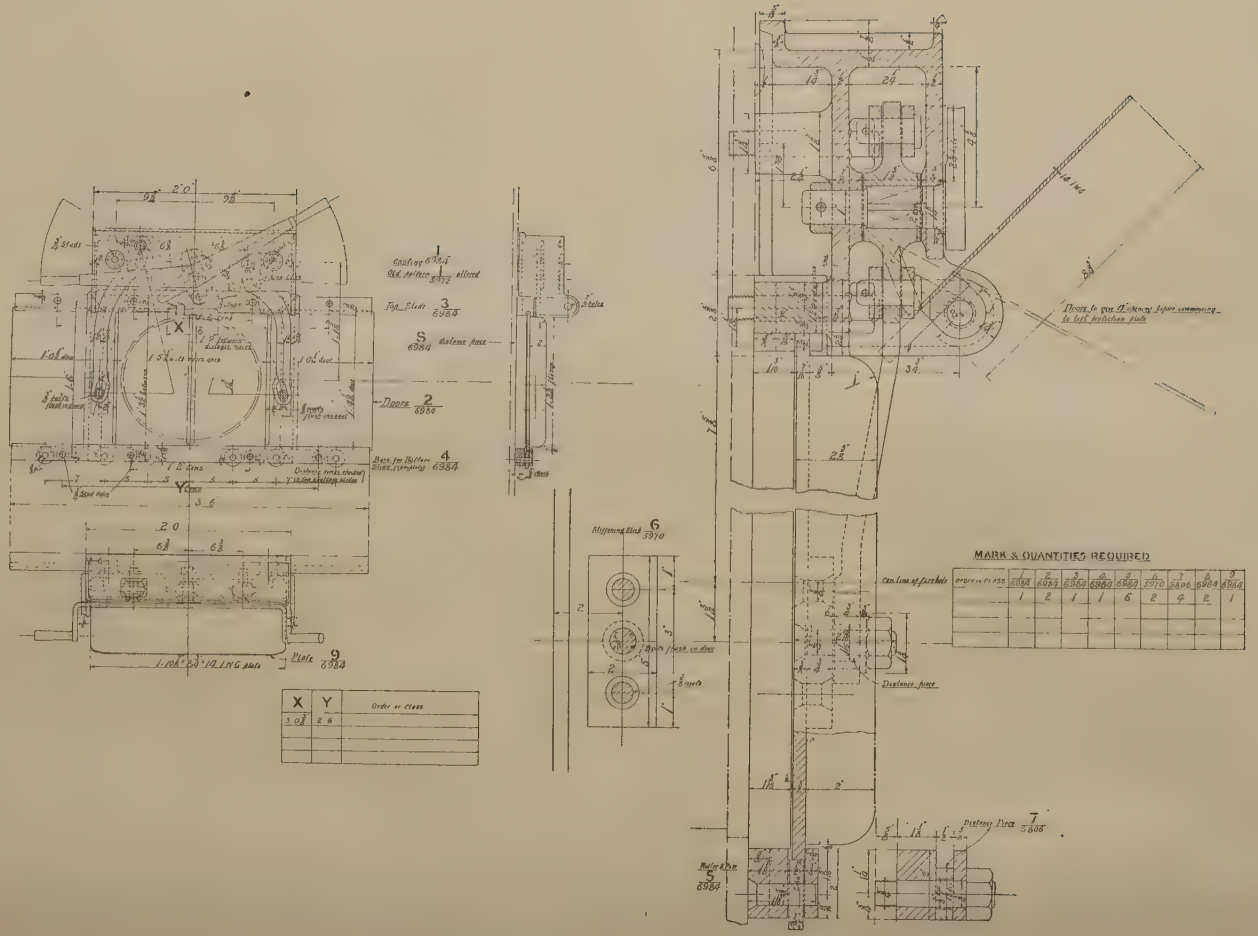

MARK & QUANTITIES REQUIRED
Door 2 6989
Plate 9 6984
Distance Piece 7 5605
Stiffening Plate 6 5970
Distance Piece
Rivets for gun A clearway before commencing to bolt hornplate plate
X Y Order or Class
3 0 2 6

Fig. 9. — Midland Railway. — Arrangement of fire-door.

Midland Railway	On five compound engines a small portion of the grate has been arranged to drop, but the practice has not been extended.
Eastern Bengal State Railway	Yes.
Great Indian Peninsula Railway	Some came out from England, but were not satisfactory and were removed.
Oudh & Rohilkhand Railway	The new engines are fitted with rocking grates.
Southern Mahratta Railway	A few engines are fitted with rocking grates, but they do not work satisfactorily.
Central South African Railways	All our boilers are fitted with rocking and drop grates.

8. — *Intermediate supports.*

The majority of the Administrations use no intermediate supports for any boilers, and it may be said that the omission of these is the general practice. The Great Western, Natal Government and Central South African Railways, however, employ a support of some kind with certain boilers having long barrels.

9. — *Smoke-box tube-plates of drumhead or extension type.*

The extension tube-plate is the most commonly used, though the Great Western and Cape Government Railways are using the drumhead type in their recent engines.

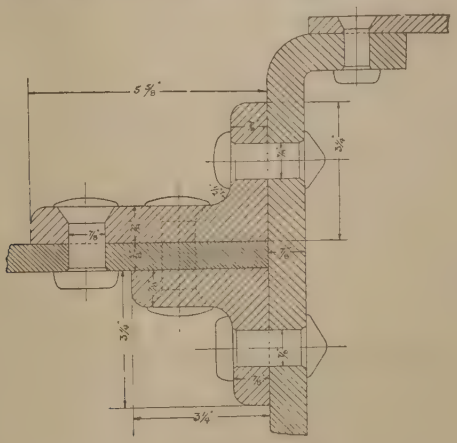


Fig. 10. — Hull & Barnsley Railway. — Boiler barrel to smoke-box tube-plate angle ring.

The use of the extension tube-plate is intended to give greater flexibility to the boiler and to reduce grooving by the absence of the flange at the bottom of the barrel.

General points in design.

TABLE 1.

NAMES OF ADMINISTRATIONS.	Whether Belpaire or round-topped boilers are used.	Whether roof-bars or radial stays are used in round-topped boilers.	Fire-box material.	Shape and size of fire-hole.	Fire-hole joint.	Proportion between.			Whether drumhead or extension tube-plates are used.
						Grate area.	Air space in grate.	Total tube area (cross section.)	
New South Wales Government Railways.	Both.	Both. (Principally roof-bars.)	Copper. (Steel tried.)	Circular: 15 1/2 inches diameter.	Rivetted ring-joint.	...	...	...	Both. (Latter preferred.)
Tasmanian Government Railways.	Both.	Both.	Copper.	Circular: 13 1/2 inches.	Rivetted ring-joint.	1	...	0·28	Both.
Western Australian Government Railways.	Both. (Latest round-topped).	Both.	Copper.	Circular: 14 inches.	Rivetted ring-joint.	1	0·36	0·17	Both.
Caledonian Railway	Round-topped.	Both. (Principally roof-bars.)	Copper and steel. (Steel now.)	Rectangular: 18×14 inches.	Rivetted ring-joint.	1	0·225	0·15	Both.
Furness Railway	Round-topped.	Roof-bars.	Copper.	Oval: 14×10 3/4 inches.	Rivetted ring-joint.	1	0·42	0·178	Extension tube-plate.
Great Central Railway	Both. (Belpaire now.)	Roof-bars.	Copper and steel.	Circular: 14 inches.	...	1	0·242	0·105	Extension tube-plate.
Great Eastern Railway	Both.	Both.	Copper and steel.	Circular: 16 inches.	Rivetted ring-joint.	1	0·393	0·169	Extension tube-plate.
Great Western Railway . . .	Both.	Both.	Copper melloid and steel.	Circular: 15 inches.	Flanged joint.	...	...	...	Both. (Drumhead now.)
Hull & Barnsley Railway . . .	Both.	Radial stays.	Copper.	Rectangular: 17×11 1/2 inches.	Rivetted ring-joint.	1 1	0·203 0·261	0·185 0·173	Extension tube-plate.
Lancashire & Yorkshire Railway.	Both. (Belpaire now.)	Roof-bars.	Copper.	Circular: 13 1/2 inches.	Flanged joint.	1	0·33	0·166	Both. (Drumhead now.)
London & North Western Railway.	Round-topped.	Roof-bars.	Copper and steel.	Circular: 14 inches.	Flanged joint.	Express passenger: 1	0·233	0·196	Extension tube-plate.

North Eastern Railway. . . .	Round-topped.	Both.	Copper. (Iron tried.)	Circular: 15 inches.	Flanged joint.	1 ...	0·392 ...	0·129 ...	Both.
South Eastern & Chatham Railway.	Both.	Roof-bars.	Copper.	Circular.	Rivetted ring-joint.	1	0·378	0·154	Extension tube-plate.
Taff Vale Railway	Round-topped.	Both.	Copper.	Oval: 15 × 12 inches.	Rivetted ring joint.	1	0·319	0·139	Extension tube-plate.
Eastern Bengal State Railway .	Both.	Roof-bars.	Copper.	Rectangular: 16 × 13 inches.	Rivetted ring-joint.	1	0·625	...	Extension tube-plate.
East Indian Railway	Both.	Roof-bars.	Copper.	Rectangular: 16 × 13 inches.	Rivetted ring-joint.	Express passenger: 1 Heavy mineral: 1 Ordinary goods: 1	0·51 0·625 0·526	... ...	Extension tube-plate.
Great Indian Peninsula Railway.	Both.	Roof bars.	Copper.	Oval: 15 × 12 inches.	Rivetted ring joint.	1	0·433	0·169	Extension tube-plate.
North Western Railway (India) .	Both.	Roof-bars.	Copper.	Oval:	Rivetted ring-joint.	1	0·53	...	Drumhead.
Oudh & Rohilkhand Railway. (State Railway of India) . , .	Both.	Roof-bars.	Copper.	Rectangular: 16 × 13 inches.	...	...	...	...	Extension tube-plate.
Southern Mahratta Railway . .	Belpaire.	Roof-bars.	Steel and copper.	Rectangular: 15 1/2 × 13 1/2 inches.	Rivetted ring-joint.	1	0·266	0·109 (not through ferrules.)	Extension tube-plate.
Cape Government Railways , ,	Round-topped.	Radial stays.	Steel and copper.	Rectangular: 15 × 12 inches.	Flanged joint.	...	...	...	Both. (Drumhead now.)
Central South African Railways.	Both.	Radial stays.	Copper.	Circular, rectangular and oval.	Rivetted ring-joint.	1 1	0·445 0·465	0·161 0·0815	Both. (Extension tube-plate now.)
* Natal Government Railways , .	Both. (Belpaire now.)	Radial stays.	Copper and steel.	Circular: 13 1/2 inches.	Rivetted ring-joint.	1	...	0·28	Both.

The grooving is, however, by no means entirely obviated. The Hull & Barnsley Railway use this type of plate, and have been so much troubled with grooving that to prevent it they have adopted the use of an internal angle-iron ring round the tube-plate (fig. 10).

10. — *Tubes and tube-plates. — Arrangement and effects of working. Tube material and reasons for adoption.*

The tube material used by the various Administrations will be seen from table 2. The general conclusion reached from the replies is that steel is being employed on railways or sections of railways where the water used does not cause excessive pitting of the tubes. Where pitting is troublesome, steel has either not been tried or has been abandoned. The Lancashire & Yorkshire and North Eastern Railways use steel tubes in good, and copper in inferior water districts, while the Western Australian Government Railways, Eastern Bengal State Railway, Oudh & Rohilkhand Railway and Southern Mahratta Railway, have tried, but have now ceased to use steel because of pitting and corrosion. In India, brass is by far the most largely used material, but in South Africa steel is being used to some extent, and under good water conditions gives satisfaction. The use of steel for tubes on British Railways is on the increase. The late high price of copper is probably a factor in this change, but there are advantages claimed for steel tubes, such, for instance, as keeping the fire-box tube-plate a better shape, prevention of leakage in long tubes, the possibility of sound expansion and beading, and that, unlike brass tubes, there is very little tendency for them of break off inside the fire-box tube-plate with high boiler pressures. The use of steel tubes should, moreover, tend to a decrease of the corrosion resulting from galvanic action. Against these advantages must still be set the fact of the much lower heat-conducting power of steel than of copper; and although the price of copper is much the greater, and in consequence of this the interest on capital outlay reaches a higher figure, the value of the scrap copper is a comparatively high one, while that of the steel is very low.

Percentage composition of brass tubes.

ADMINISTRATIONS.	COPPER.	ZINC.
Midland Railway.	70 per cent.	30 per cent.
South Eastern & Chatham Railway	$66\frac{2}{3}$ —	$33\frac{1}{3}$ —
Taff Vale Railway	70 —	30 —
Central South African Government Railways	70 —	30 —

11. — *Tube dimensions.*

These will be seen on reference to table 2 and call for no special remark, but it may generally be taken that the diameter has increased of recent years.

12. — *Method and order of fixing tubes.*

A roller tube-expander of some type is used in every case, generally the Dudgeon or Thomson-Wicksteed. The London & North Western Railway bellmouth their tubes with a drift, after roller-expanding (fig. 11). Some of the Administrations specify no particular order in the expansion of the tubes, and amongst those where such order is specified there is considerable difference shewn. The object in the latter case is to effectually secure the tubes against leakage with the least and most uniform distortion of the fire-box tube-plate. The Lancashire & Yorkshire Railway method is shewn in figure 12. The Midland Railway method is to secure twelve tubes at each of the four corners, then twelve in the middle, and then work outwards in concentric rings from these latter. The Caledonian Railway and East Indian Railway work from the centre outwards, and the South Eastern & Chatham Railway from centre outwards in vertical rows, while the North Western Railway (India), Central South African Railways and the Great Eastern Railway work from the outside towards the centre.

13. — *Serve tubes.*

These are not used at the present time by any of the Administrations reporting, several having tried but abandoned them as being unsuitable for their purpose, principally on account of the excessively troublesome leakage which frequently occurs after short service. The report issued by the Pennsylvania Railroad of the tests of a locomotive fitted with these tubes at the Louisiana Purchase Exposition of 1904 shewed that there was no increased economy resulting from their use.

14*a*. — *Pitting of steel or iron tubes and steps taken to counteract it.*

It may be said that the large majority of the Railways replying who use steel tubes, have been troubled with pitting. In one or two cases a water-softening process has been introduced to remedy this defect.

The question of pitting in general will be dealt with under section C, but the pitting of the exterior surface of the tubes is due to the same cause as that which results in pitting of the boiler barrel. The Great Indian Peninsula Railway found that some lap-welded tubes experimented with pitted badly after a very short time; their use was discontinued and solid drawn tubes used in their place, and these have proved satisfactory to date. The pitting appears to be worst near the feed-water delivery and the fire-box tube-plate, and to renew the tube in this latter part the

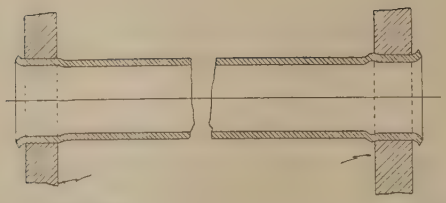
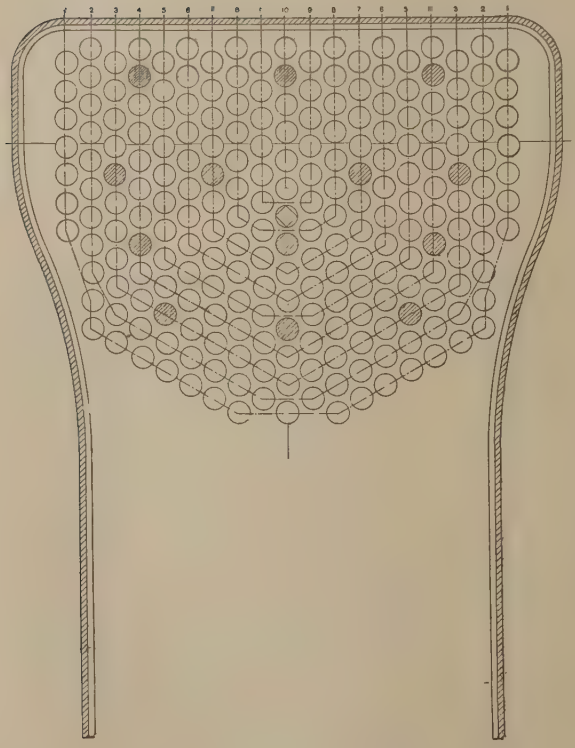


Fig. 11. — London & North Western Railway. — Boiler tube.



Tube expanding.

It has been found as the result of a series of experiments on different methods of expanding tubes, that the following order gives, at the same time, the least and most uniform distortion to the copper fire-box tube-plate.

The tubes shown → ◍ are to be expanded first, in any order, then follow the — · — lines from No. 1 to No. 9 and finish on row No. 10.

Should the arrangement of the tubes be somewhat different in any particular boiler, this method of expanding must be followed as closely as possible.

Fig. 12. — Lancashire & Yorkshire Railway.

Great Central Railway cut off the end and weld a new piece on, whilst other Administrations braze a new end on. The Natal Government Railways are finding that they can extend the use of steel tubes by softening their water, and the North Eastern Railway soften their water to prevent this defect. The Lancashire & Yorkshire Railway find that their boilers in some cases suffer from isolated small pit marks, and to prevent the whole tube from having to be scrapped for so small a defect, weld soft iron into the cavity by means of an Oxy-Acetylene flame.

14*b*. — *Excessive wear or fracture of copper or brass tubes just inside the copper tubeplate.*

The causes to which these defects are attributed are :

1° Bad water causing heavy scale on tubes;
2° High boiler pressures.

The trouble is greatest in the case of brass tubes, which pit in their interior, just inside the ferrule, at the fire-box end. The Hull and Barnsley Railway find that their copper tubes get thin on the upper side, just inside the ferrule, which they state is caused by the flame striking upward before taking a horizontal direction. Brass tubes become worn in the same way, and this is generally considered to be caused by the erosive action of solid particles carried from the fire-box. See figure 13, for section of worn or eroded brass tube.

In the case of copper tubes, the Midland Railway have a plant for re-drawing those tubes which are deformed at the smoke-box-end when they are taken out of the boiler. This end is cut off and the tube is re-drawn in dies so as to give the desired length, being reduced about $^1/_{16}$ inch in diameter during the process. The Great Indian Peninsula Railway cut off the fire-box end of their brass tubes when defective and piece a fresh end on, the position of the tubes being reversed when put back in the boiler.

Galvanised steel tubes. — Only seven of the twenty-five Administrations who have replied have tried these tubes. Of these, the London & North Western Railway have ceased to use them, as the results were not satisfactory, the Midland, Central South African, Lancashire & Yorkshire, and South Eastern and Chatham Railways are now giving them a trial, the Great Central Railway finds that pitting is prevented by their use, and the Caledonian Railway has used then since 1904 with favourable results.

15. — *Use of ferrules.*

Ferrules are used with the double object of keeping the tubes tight and protecting the ends from the action of the fire. In no case are they used at the smoke-box end. The general practice is to use ferrules with brass and copper tubes, but not with steel tubes; in the cases of three Administrations, however, — the London

& North Western, Great Central & Furness Railways, — after steel tubes have been in service for some time, ferrules are used to ensure tightness.

Particulars of ferrules.

ADMINISTRATIONS.	TAPER OF CONE.	THICKNESS.
New South Wales Government Railways	1 in 32	1/8 inch full.
Tasmanian Government Railways	1 in 20	5/32 inch.
Western Australian Government Raiways. . . .	1 in 40	11 S. W. G. (0·116 inch).
Furness Railway	1 in 16	13 W. G. (0·092 inch).
Great Central Railway	1 in 32	11 S. W. G. (0·116 inch).
Hull & Barnsley Railway.	1 in 20	0·180 and 0·156 inch.
Lancashire & Yorkshire Railway	1 in 16	1/8 inch.
London & North Western Railway.	1 in 80	1/8 inch.
Midland Railway	1 in 26·5	Varies with size.
Taff Vale Railway.	1 in 40	1/8 inch.
Eastern Bengal State Railway	1 in 20	1/8 inch.
East Indian Railway	1 in 20	1/8 inch.
North Western Railway (India).	1 in 20	11 W. G. (0·116 inch).
Oudh & Rohilkhand Railway	1 in 20	3/16 inch.
Central South African Railways	1 in 20	3/16 inch.
Natal Government Railways	1 in 24	9 W. G. (0·144 inch).

Beading of tube-ends and results. — Very conflicting evidence is given regarding the benefits to be derived from the beading of tube-ends, but the following replies from the Indian Administrations may be taken as typical of those using brass tubes :

1° *Eastern Bengal State Railway.* — Beading is done at the fire-box tube-plate, it helps to prevent corrosion and makes tubes tighter;

2° *East Indian State Railway.* — Practice discontinued, as it was found troublesome and gave no compensating benefit;

3° *Great Indian Peninsula Railway.* — Engines from England have beaded ends at fire-box, but we find they readily burn off.

The preceding replies refer to brass tubes, but with steel tubes beading appears to give greater satisfaction, as the Great Central, Great Western, London Tilbury & Southend and Cape Government Railways who use only steel tubes, all obtain good results. The beading protects the edges of the holes in the tube-plate from the action of the fire, and at the same time assists in ensuring tightness of the tubes

and staying of the tube-plate. Its use is generally confined to the fire-box end, but in one or two cases a beading is also put on at the smoke-box end.

16. — *Arrangement of tubes in the tube-plate.*

The vertical arrangement of the rows of tubes is the most common. About three-fifths of the Administrations replying adopt this, whilst the others arrange the tubes horizontally. On a few Railways both methods are in use. The reasons put forward for the adoption of the vertical arrangement are that this method gives better circulation and that the scale formed falls more readily to the bottom of the boiler barrel. The North Eastern Railway find that the tube-plates last longer, and the Western Australian Government Railways state that there is less disturbance of the fire-box crown sling stays with the tubes in vertical rows. The advantages claimed for the horizontal arrangement are that it is more satisfactory for washing-out purposes (Eastern Bengal State Railway while the London Tilbury & Southend Railway claim for it the advantage generally held to apply to the vertical arrangement, *viz.*, that of more efficient circulation. The Great Indian Peninsula Railway use both methods and find each satisfactory.

Space allowed between tubes. — This is shewn in table 2, and it will be noticed that the most frequent dimension is $^3/_4$ inch. Given certain conditions of working, it seems probable that there is some minimum width of " bridge " below which it is inadvisable to go, or serious trouble will result from cracking between the tube-holes. This is found to be the case in practice, as a tube-plate which will give trouble with an $^{11}/_{16}$ inch " bridge " may stand well if this be increased to $^3/_4$ inch.

There seems to be a tendency to increase the space between the tubes in order that the possibility of the accumulation of dirt may be minimised and washing-out can be more thorough; for though by this method there is a loss of heating surface, this may be compensated for by other more satisfactory working conditions. Special spacing of the tubes round the tube-plate edges is referred to under question 18.

17. — *Pressures above 180 lbs. per square inch and special means to cope with them.*

Nine of the Administrations replying use pressures over 180 lbs. per square inch (table 2) the highest being 225 lbs., used on the Great Western Railway. A pressure of 220 lbs. per square inch is used by the Midland Railway on their three-cylinder compounds. The difficulties recorded with regard to these high pressures are said to be few, and apparently no special means are generally used to obviate any defects proceeding therefrom. The Central South African Railways say " The boilers of our " 9^{th}, 10^{th}, and 11^{th} class engines work at a pressure of 200 lbs. per square inch. " A good deal of trouble has been experienced with the fire-box tube-plates of these " engines. Also difficulty has been experienced in keeping their tubes tight,

Tubes, stay material and boiler pressures.

TABLE 2.

NAMES OF ADMINISTRATIONS.	Tube material.	Tube dimensions.			Arrangement of tubes in vertical or horizontal rows.	Space between tubes.	Stay material.	Boiler pressure. 180 lb. per square inch and over.
		Outside diameter.	Thickness fire-box end.	Thickness smoke-box end.				
		Inches.	Inches.	Inches.		Inches.		
New South Wales Government Railways.	Copper.	1 7/8.	10 B. W. G. : 0·134.	12 B. W. G. : 0·109.	Horizontal.	11/16 to 3/4.	Copper.	...
Tasmanian Government Railways.	Brass and coppercoated steel.	1 3/4.	...	12 B. W. G. : 0·109.	Horizontal.	5/8.	Copper and stone's bronze.	...
Western Australian Government Railways.	Brass and copper.	1 3/4.	10 S. W. G. : 0·128. 11 S. W. G. : 0·116.	12 S. W. G. : 0·104. 12 S. W. G. : 0·104.	Vertical.	5/8 to 13/16.	Copper, (bronze tried).	200.
Caledonian Railway	Galvanised steel.	1 3/4 and 2.	10 S. W. G. : 0·128. 11 S. W. G. : 0·116.	10 S. W. G. : 0·128. 11 S. W. G. : 0·116.	Vertical.	5/8 to 3/4.	Stone's bronze and melloid.	200.
Furness Railway	Iron and steel.	1 3/4.	...	...	Vertical.	...	Copper and bronze.	...
Great Central Railway	Steel.	1 3/4, 1 7/8 and 2.	11 S. W. G. : 0·116.	11 S. W. G. : 0 116.	Vertical generally.	13/16 to 7/8.	Copper and stone's bronze.	200.
Great Eastern Railway	Steel.	1 3/4.	13 S. W. G. : 0·092.	13 S. W. G. : 0·092.	Both.	11/16.	Stone's bronze.	...
Great Western Railway. . . .	Steel.	1 5/8 and 2.	8 S. W. G. : 0·16. 10 S. W. G. . 0·128.	10 S. W. G. : 0·128. 10 S. W. G. : 0·128.	Vertical.	5/8 smoke-box. 3/4 fire-box.	Copper, melloid, Stone's bronze and iron.	200 and 225.
Hull & Barnsley Railway . . .	Copper.	1 3/4 and 2.	11 B. W. G. : 0·12. 1 B. W. G. : 0·134.	13 B. W. G. : 0·095. 12 B. W. G. : 0·109.	Vertical.	11/16 and 3/4.	Copper.	...
Lancashire & Yorkshire Railway.	Steel and copper.	2.	11 S. W. G. : 0·116.	11 S. W. G. : 0·116.	Vertical.	11/16 and 3/4.	Copper.	...

Midland Railway	Brass, copper and galvanised steel.	Steel 1 5/8 and 1 3/4.	12 S. W. G. : 0·104.	12 S. W. G. : 0·104.	Both.	5/8.	Copper and bronze.	220.
North Eastern Railway	Steel and copper.	1 3/4.	11 S. W. G. : 0·116.	13 S. W. G. : 0·092.	Both; (vertical now).	5/8 to 3/4.	Copper (principally).	...
South Eastern & Chatham Railway.	Brass and patent alloy.	1 3/4.	11 B. W. G. : 0·12.	13 B. W. G. : 0·095.	Horizontal.	11/16.	Stone's bronze.	...
Taff Vale Railway	Brass.	1 3/4.	11 B. W. G. : 0.12.	13 B. W. G. : 0·095.	Diagonal.	1.	Copper, iron and steel.	...
Eastern Bengal State Railway. .	Brass.	1 3/4.	11 S. W. G. : 0·116.	13 S. W. G. : 0·092.	Horizontal.	3/4.	Copper and bronze.	...
East Indian Railway.	Brass.	1 3/4 and 2.	11 B. W. G. : 0·12. 10 B. W. G. : 0·134.	13 B. W. G. : 0·095. 12 B. W. G. : 0·109.	Horizontal.	3/4.	Copper(Stone's bronze tried).	...
Great Indian Peninsula Railway .	Brass and steel.	Brass : 2 1/4, 2 and 1 3/4. Steel : 2 1/4.	10 S. W. G. : 0·128. 9 S. W. G. : 0·144. 9 S. W. G. : 0·144. 10 S. W. G. : 0 128.	12 S. W. G. : 0·104. 12 S. W. G. : 0·104. 12 S. W. G. : 0·104. 10 S. W. G. : 0·128.	Both.	3/4.	Copper.	180.
North Western Railway (State Railway of India).	Brass.	2 1/4, 2 and 1 3/4.	11 S. W. G. : 0·116.	13 S. W. G. : 0·092.	Vertical.	3/4.	Copper (Stone's bronze tried).	...
Oudh & Rohilkhand Railway. .	Brass and steel.	2 1/4.	10 B. W. G. : 0·134.	12 B. W. G. : 0·109.	Horizontal.	3/4.	Stone's phosphor bronze and Lowmoor iron.	180.
Southern Mahratta Railway . .	Brass.	1 3/4.	11 S. W. G. : 0·116.	13 S. W. G. : 0·092.	Horizontal.	3/4.	Copper.	180.
Cape Government Railways . .	Mild steel and charcoal iron.	1 3/4, 1 7/8, 2 and 2 1/4.	11 S. W. G. : 0·116.	...	Vertical.	3/4, 7/8 and 1.	Copper and iron.	200.
Central South African Railways .	Brass, steel and charcoal iron.	Brass : 2. steel : 2 1/4, charcoal iron : 2.	10 B. W. G. : 0·134. 9 B. W. G. . 0·148. 10 B. W. G. : 0·134.	12 B. W. G. : 0·109. 12 B. W. G. : 0·109. 12 B. W. G. : 0·109.	Vertical.	7/8.	Muntz metal Company's special nickel copper M. N. 2 alloy. Stone's bronze and copper.	200.
Natal Government Railways . .	Steel and red metal.	Steel : 2, red metal : 2	11 S. W. G. : 0·116. 10 S. W. G. : 0·128.	11 S. W. G. : 0·116. 12 S. W. G. : 0·104.	Horizontal.	11/16.	Stone's special bronze.	200.

" necessitating frequent re-rolling, with consequent distortion of the tube-holes. It " is considered that high steam-pressure is the main cause of this trouble."

" Inward Expansion " of tubes is a method in use on the Great Western Railway with their high-pressure boilers. This method consists in providing expanders which are used in the reverse way to those ordinarily used, resulting in the tube being expended to its greatest diameter just inside the barrel, or immediately on the front side of the fire-box tube-plate. By the use of this method, the Great Western Railway claim an almost entire immunity from tube troubles. It is to be observed that this Company uses steel tubes, but with copper the case is different. It is a common practice with these latter, when they become burnt at the fire-box end, to knock them through slightly from the smoke-box end, thus increasing the length of time the tubes are in service. With " inward expansion ", it is obvious that this method cannot be adopted.

The London & North Western Railway have been using 200 lbs. per square inch on their compounds, but these engines are being superseded by simple engines at lower pressures. The Midland Railway find that the life of the fire-box stays is considerably less with these high pressures than with those below 180 lbs. per square inch. This latter Administration, using copper tubes and iron longitudinal stays, found that with their boilers working at 220 lbs. the distortion of the fire-box tube-plate was considerable. This trouble was reduced materially by substituting either bronze longitudinal stays for iron, or steel tubes for copper. They have had engines running for several years at 195 to 200 lbs. pressure, and have experienced no special trouble with them.

18. — *Special spacing of tubes or stays to prevent cracked corners of tube-plate.*

With regard to special spacing of tubes in the tube-plate, the Midland, Lancashire & Yorkshire, and Southern Mahratta Railways pitch their tubes wider apart near the flange, while the Great Central Railway make a rule of never allowing any tube to come within 1 $^1/_2$ inches of the flange. Another method adopted as a means of decreasing the tendency to crack at the corners is to swage down the tubes in the outside rows just before entering the fire-box tube-plate. This method is in use on the Great Indian Peninsula, North Western (India) and London & North Western Railways. The Natal Government Railways reduce the diameter of the whole of their tubes in the fire-box tube-plate, but in their case it is with the object of preventing cracking of the bridges. In the swaging down of these tubes the reduction in diameter is usually $^1/_4$ inch.

No special spacing of stays is mentioned as having been tried by any Administration.

Cold-hammering. — The only Administration replying that has tried this method of treating the copper tube-plate is the Midland Railway; their experience has not been of sufficient duration to give any definite results, but it does not appear that it

will prove of any advantage. The method employed was to obtain the copper tube-plate $^1/_8$ inch thicker than the finished size, and under a small steam hammer reduce this to the required thickness, the object being to harden the copper and give a greater resistance to distortion of the tube-holes during the expansion of tubes, thus ensuring greater tightness.

19. — *Use and advantages of extended smoke-boxes.*

Some difficulty may have been experienced in replying to this question with regard to what should be considered as an "extended" smoke-box. Twelve out of the twenty-five Administrations state that they do not use extended smoke-boxes, but one of these, the North Western Railway India uses "fairly long" boxes with very satisfactory results. The Western Australian Government Railways reply thus regarding their advantages : *a*) "Greater area for smoke-box ash, thereby a longer run before "cleaning smoke-box, *b*) greater area through the meshes of our spark-arresting appli-"ances and less percentage of dead area, *c*) generally better steaming of locomotive."

The other advantages claimed for the extended smoke-box are, reduction of spark-ejection by equalising the pulsations of the blast on the fire, less wear of front plates and door, less drawing of air through smoke-box door (other conditions being unaltered), prevention of blocking up of lower rows of tubes with ashes, and less damage done by high temperature in the smoke-box.

20. — *Steam-domes or other device to obtain dry steam.*

All Administrations are using steam-domes, with the exception of the Great Western and Hull & Barnsley Railways. In the former, the steam is "taken by a bifurcated pipe from the top of fire-box", and the Hull & Barnsley Railway use an internal pipe fixed longitudinally about $^1/_2$ inch below top of boiler and perforated along the upper surface with rows of holes $^5/_{16}$ inch in diameter. It is to be noticed that in the Great Western Railway Co's boiler built without a steam-dome (fig. 14), the depth of the space over the fire-box is two feet, this depth being obtained by the coning of the plates on the upper side of the barrel.

21. — *Lagging material.*

The various lagging materials used are :

1. — Asbestos.
2. — Blue asbestos mattress.
3. — White asbestos mattress.
4. — Asbestos cement.
5. — Asbestos paint on felt cloth.
6. — Magnesia-asbestos blocks.
7. — Silicate cotton (Slag wool).
8. — Magnesia clothing.
9. — Felt clothing.
10. — Wood.
11. — Confined air. (Distance pieces of pine.)
12. — "Limpit mattress".
13. — "Leroy's" composition.
14. — Asbestos blanket.

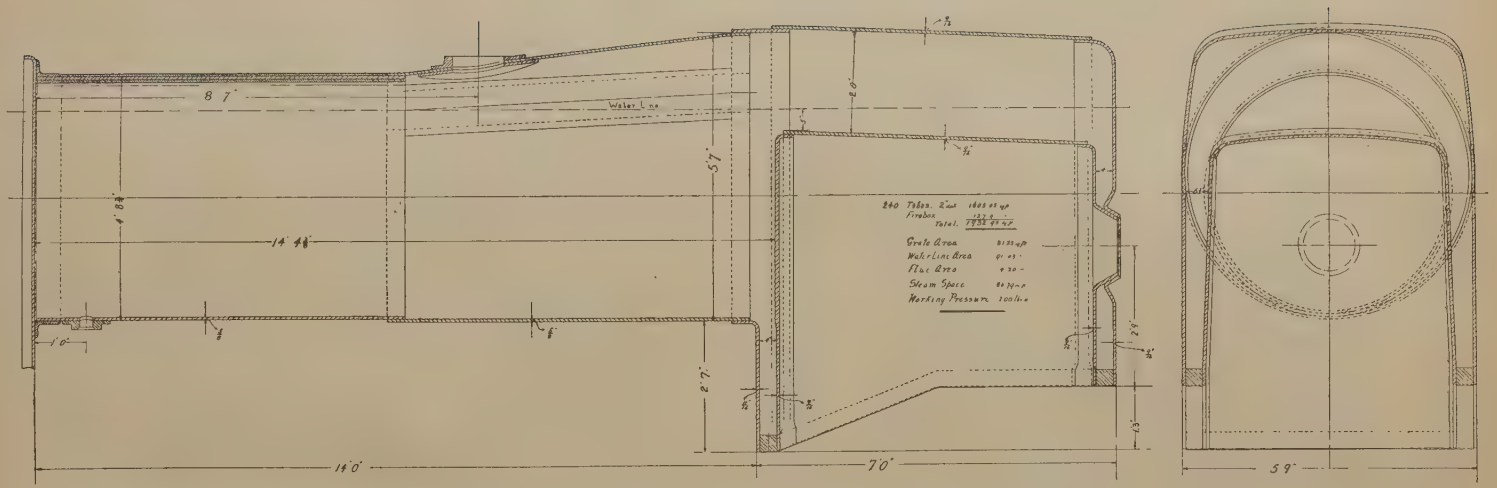


Fig. 14. — Great Western Railway. — Arrangement of boiler.

It will be seen from this list that some form or preparation of asbestos is the most commonly used material for lagging purposes.

Fourteen of the Administrations lag their boilers inside the cabs. The Midland Railway do not lag the portion of the boiler inside the cab, except in the case of some of their Belpaire engines.

22. — *Thermal storage and advantages derived therefrom.*

Only the Lancashire & Yorkshire Railway and the Taff Vale Railway have tried the Druitt-Halpin system of thermal storage. The former Railway are still using the system, and hope to obtain therefrom considerably less pitting and corrosion of boiler plates. The Taff Vale Railway have tried the system, but give no particulars of the results obtained.

From the drawing (fig. 15) supplied by the Lancashire & Yorkshire Railway, it will be seen that the thermal storage tank is fixed immediately behind the chimney on the top of the boiler barrel. It is 12 ft. 2 in. long, and the dome-shaped passage from the lower barrel connects with the tank. This passage is open at the top, and there is thus free steam-communication between the boiler barrel and the top of the storage tank. The whole of the feed-water is passed through the delivery pipe into the storage tank, from which it can pass into the boiler, either by the overflow pipe shewn or through a valve controlled from the cab, in either case entering the boiler by the same pipe. When the engine is not being heavily worked, the storage tank may be filled and the surplus steam generated in the boiler serves the function of heating up this feed-water so as to prepare it for entering the boiler at a high temperature when required. It will thus be seen that the maximum amount of pitting and corrosion will take place in the thermal storage tank rather than in the boiler proper, and the life of the boiler should, therefore, be increased. The storage tank is simple in construction, so that if badly corroded it can be easily changed. The Administrations reporting have not had sufficient experience to allow of their expressing a definite opinion of the merits of the method. Further particulars of the boilers fitted with thermal storage as used on the Lancashire & Yorkshire Railway are given below :

Tube heating-surface	1,103·00 square feet.
Fire-box heating-surface	107·68 — —
Total.	1,210·68 square feet.
Grate-area	18·75
Flue-area	2·70
Steam-space	43 cubic feet.
Capacity of storage tank	420 gallons.

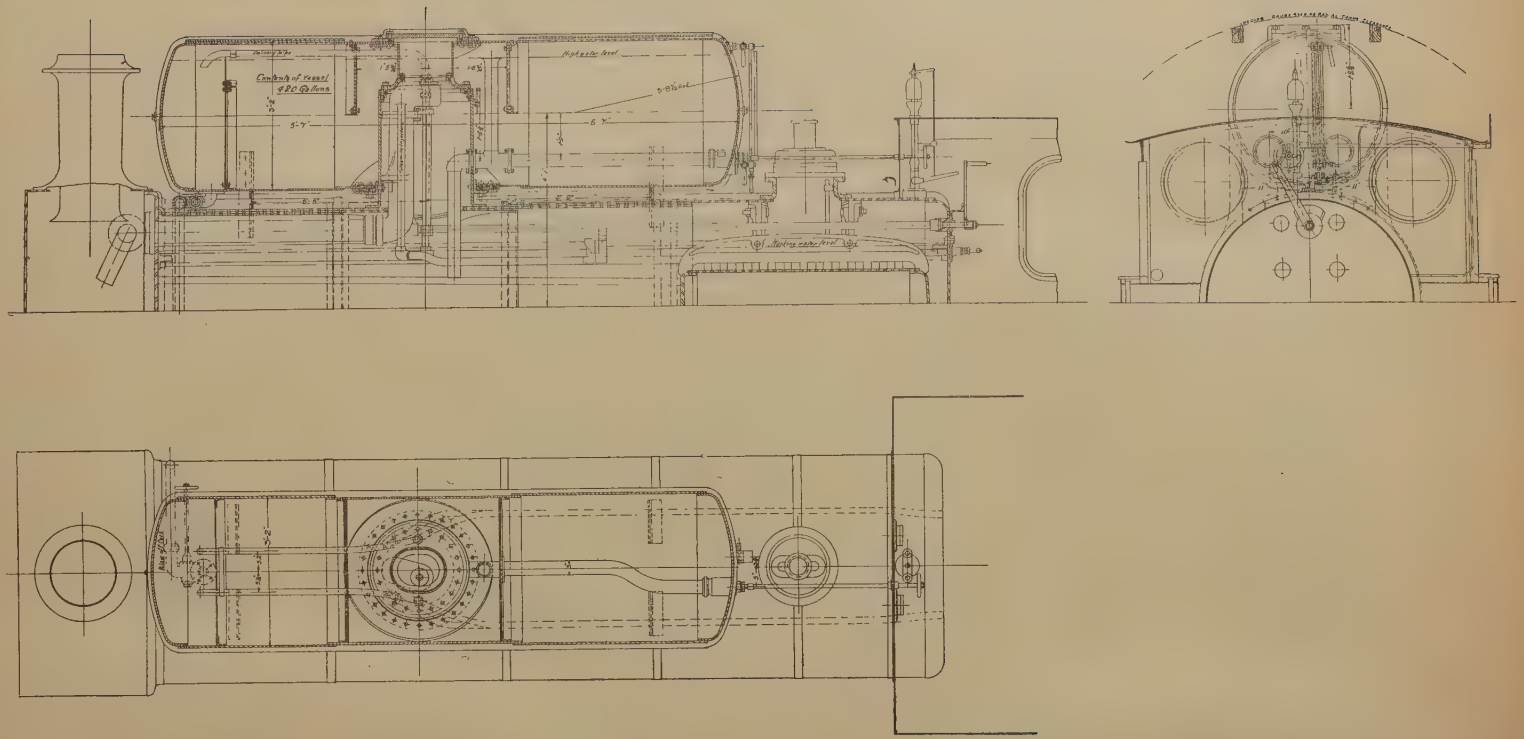


Fig. 15. — Lancashire & Yorkshire Railway. — Arrangement of thermal storage tank.

Mr. Churchward of the Great Western Railway in his paper (1) on " Large Locomotive Boilers " pointed out that the same advantages, as far as thermal storage itself goes, can be obtained by increasing the size of the steam-space in the boiler. A sketch (fig. 14) shews how this is done on this Railway.

B. — Boilers with water-tubes. — Steam superheaters and valve gear for superheated steam. — Feed water heaters.

Boilers with water-tubes.

None of the Administrations replying use water-tube boilers, but the East Indian, Central South African and Cape Government Railways use Drummond water-tubes in some of their fire-boxes. The arrangement of these water-tubes in a fire-box is shewn in figure 16. The tubes are placed in one or two nests across the fire-box, immediately above the brick arch, so that they are in the passage-way of the gases to the smoke-tubes. If the fire-box is small, one nest is used, and if large, two. In either case, the tubes are given a slope from one side of the fire-box to the other of about 4 inches, but if two nests are used, the tubes in one set are inclined in a different direction to the others. Steel-castings, with flanges for connection with the outside wrapper-plate and for fastening on a door, are arranged opposite the end of each nest of tubes, and the covering door is held on by means of studs, the joint being made with boiled linseed oil. The large flat surfaces of the doors are stayed with iron stays which pass through the tubes and doors, and are held by cap-nuts screwed on to their ends (fig. 16). The tubes, of which there are usually 36 in a nest, are arranged in six rows. They are 2 inches in internal diameter throughout, $^3/_{16}$ inch thick at the ends, and $^1/_8$ inch in the centre. The hole for them in the copper plate has a slight recess put in it, round the edge of the hole and half way through the plate before the tube is expanded into it, and this is said to have an excellent effect in keeping the tubes tight (fig. 17). By the addition of these tubes, the heating surface of a fire-box is increased 100 per cent, which considerably adds to the steaming capacity of the boiler. It is also observed that, owing to the better circulation set up by the addition of these water-tubes in a fire-box, the water-spaces keep very clean, thus reducing the cost of repair and adding to the life of the fire-box.

On the London & South Western Railway, boilers fitted with these tubes have been in service for over ten years with satisfactory results. These water-tubes are fitted in all new boilers, with the exception of those on which side tanks are placed,

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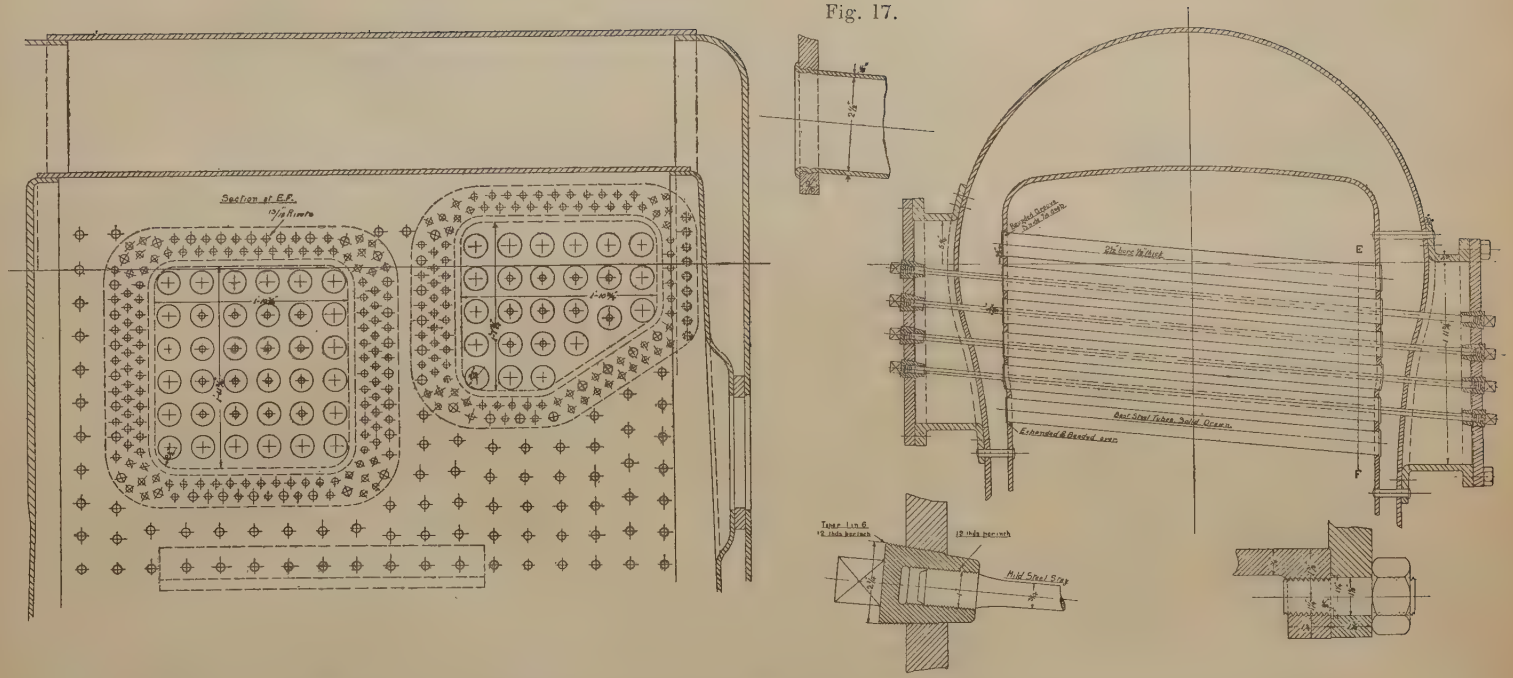
(1) *Proc. Inst. Mech. Eng.*, 1906, p. 224.

Fig. 17.


Section at F.F.
13/16 Rivets
Tapered Screwed Stays 18 Threads per inch
Fire Box Tube Plate
Best Steel Tubes Solid Drawn.
Expanded & Beaded each end
Taper 1 in 6
12 Threads per inch
Mild Steel Stay

Figs. 16 and 17. — London & South Western Railway. — Drummond's fire-box water tubes and doors.

these preventing any inspection, should this be necessary. Two hundred London & South Western engines have these tubes, of which nearly half are express passenger. It is stated that the doors are only removed under ordinary circumstances at the time the engine is shopped, and in one case, two years and four months elapsed between successive inspections. Usually, there is a coating of scale about $^1/_{16}$ inch thick at the end of the tube and about $^1/_{32}$ inch in the centre. Many tubes are said to be still running after eight to ten years service. This Company claims that the ejection of sparks is largely prevented by the tubes, and that the circulation set up by them on the fire-box sides is so good that the water-space can be made very narrow, it being not greater than 2 inches at the foundation ring.

The replies from the various Administrations relating to this subject, are as follows :

East Indian Railway. — " A few boilers are fitted with Drummond water-tubes " in the fire-box, but with coal at the price the Company gets it, the expenditure " and maintenance troubles are not justified. "

Cape Government Railways. — " We have one locomotive fitted with Drummond " water-tubes, a slightly better steamer than a similar engine without these tubes. " We have not gone further with them on account of the increased cost, and the " difficulty of getting at the fire-tubes. "

Central South African Railways. — " Thirty 8^2 class boilers are fitted with " " Drummond " water-tubes in the fire-box. These tubes do not appear to make " much difference to the steaming qualities of the boilers. Up to date, practically " no repairs have been necessary to the water-tubes. It has been noticed that the " tube-plates of these boilers have worn considerably better than the others of this " class. Our experience leads us to believe that the results obtained do not justify " the extra expense of fitting these tubes to boilers."

The Great Western Railway use fire-box water-tubes in one case where the tubes are used for supporting the brick arch.

The Brotan boiler is not used by any of the Administrations reporting. The British Mannesman Tube Co. have, however, one of these employed on a shunting Engine at their Landore (South Wales) Works.

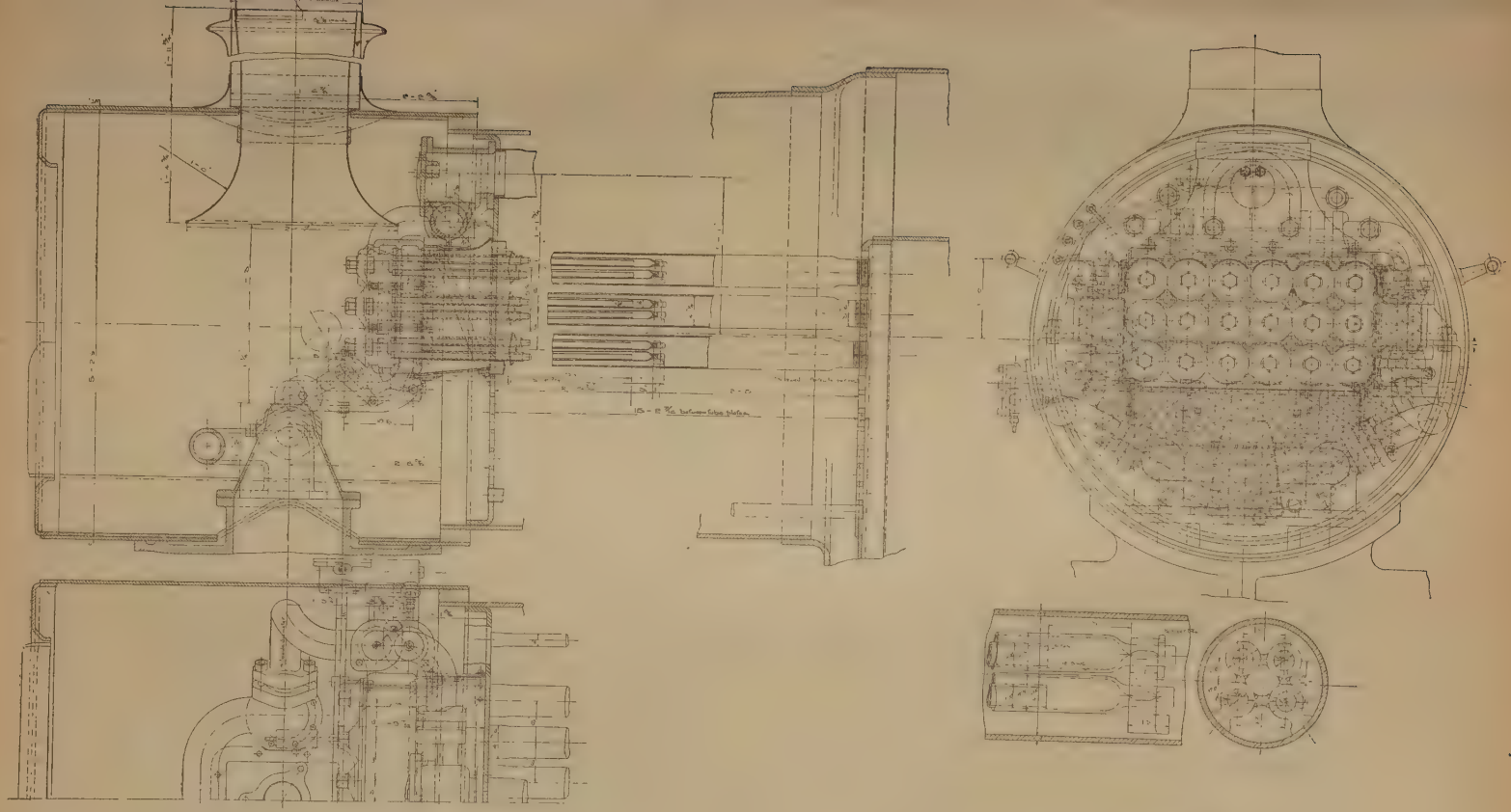
Steam superheaters. — Three only of the Administrations who have replied to the printed list of questions use superheated steam in their locomotives; these are the Lancashire & Yorkshire Railway who, at the time of sending in their report, had two locomotives in service and 25 under construction with superheaters of the Schmidt smoke-tube type; the Great Western Railway, who have six in service of the Swindon type; and the Cape Government Railways, who have two in service of the Schmidt smoke-box type. In addition to these, however, a letter has been received from the London Brighton & South Coast Railway, stating that they have ten engines fitted

*

with Schmidt's superheaters. These latter have not been in use for a sufficient length of time for reliable figures to be given with regard to their performance, but, as compared with those of the same type which have not been so fitted, they are a far stronger engine, use a good deal less water and no more coal, that is to say, they are capable of doing more work with the same amount of coal as that burnt by other engines of their class which have not been fitted with superheaters. The following is the reply received from the Cape Government Railways :

" We have two locomotives fitted with Schmidt's original design of smoke-box " superheaters. These locomotives were originally fitted with piston valves with " solid rings, but we could not get them to work satisfactorily and substituted some- " what larger valves with spring rings which work satisfactorily. These two loco- " motives have been tested against simple locomotives of the same design, with the " exception that the simple locomotives have 17 inch cylinders and the superheater " locomotives 18 $^1/_2$ inch cylinders. We could not find that there was any marked " economy in the superheater locomotives."

The Great Western locomotives are fitted with superheaters of the Swindon type. This class of superheater is one in which a steam-header having two chambers, one for superheated and one for saturated steam, is placed in the smoke-box. The superheater tubes are of the Field type and connected with this header, thence passing through smoke-tubes of 4 $^3/_4$ inches diameter. There are four of these Field tubes in each of the eighteen smoke-tubes; and the method by which they are secured is shewn in figure 18, from which it will be seen that each set of four superheater tubes may be separately dismantled for inspection or repair. The exterior tube of each double tube is expanded in the ordinary way into a small circular plate, which is drawn up by means of the single nut and bolt shewn in figure 18 to the back side of the header casting, the actual joint being made against the metallic packing ring shewn. The interior tube is similarly expanded into another circular plate, which is pulled up by the same bolt against the middle partition of the header; this joint requires no packing. The bracket used for supporting the tubes at the fire-box end may be seen in figure 18. As will be seen from the figure, an arrangement is provided for obstructing the passage of the flue gases through the superheater smoke-tubes, when no steam is passing through the superheater tubes, thus preventing the latter from being burnt. The steam from the boiler enters the front chamber of the header, and passes thence through the inner of the superheater tubes, and back to the rear chamber of the header, through the exterior superheater tubes; from this chamber there is a connection with the steam-chest, and thus the steam passes in its superheated state to the cylinders. It has been objected to these Field type of tubes, that when they are used for superheating they are fundamentally defective, inasmuch as the wet steam in the inner tube flows in the reverse direction to the superheated steam in the outer tube, and so exerts a cooling influence on the latter, thus rendering the superheating considerably less effective.



Heating surface :

72 superheater tubes 1 3/8 inches diameter	300·00 square feet.
18 fire-tubes 4 3/4 inches diameter	339·36 — —
165 — 2 — —	1,313·45 — —
Fire-box	154·34 — —
Total.	2,107·15 square feet.

Flue area :

Superheater	1·33 square feet.
Tubes	2·48 — —
Total.	3·81 square feet.

Fig. 18. — Great Western Railway. — Arrangement of superheater.

The following are the leading particulars of the locomotives to which these superheaters are applied :

	Description.
Cylinders (4)	Diameter, 14 1/4 in.; stroke, 26 in.; steam ports, 25 × 1 1/4 in.; exhaust, 25 × 3 inches.
Boiler	Barrel, 14 ft. 10 in.; diameter outside, 4 ft. 10 3/4 in. and 5 ft. 6 in.
Fire-box	Outside, 9 ft. × {5 ft. 9 in.; 4 ft. 0 in.; inside, 8 ft. 2 7/16 in. × {4 ft. 9 in., 3 ft. 2 5/8 in.; height, 6 ft. 6 3/8 in. and 5 ft. 0 3/8 in.
Tubes	72 superheater tubes. Diameter, 1 3/8 in.; length, 13 ft. 7 5/8 in.
	165 fire tubes. — 2 in.; — 15 ft. 2 7/16 in.
	18 — — — 4 3/4 in.; — 15 ft. 2 7/16 in.
Heating surface	Superheater tubes. 300·00 square feet.
	Fire tubes. 1,652·81 — —
	Fire-box tubes. 154·34 — —
	Total. 2,107·15 square feet
Area of fire-grate	27·07 square feet.
Wheels	Bogie, 3 ft. 2 in.; leading, 6 ft. 8 1/2 in.; driving, 6 ft. 8 1/2 in.; trailing, 6 ft. 8 1/2 in.
Water capacity of tender.	3,500 gallons.
Working pressure	225 lbs. per square inch.
Tractive effort	26,560 lbs.

The Great Western Railway have not increased the diameter of their cylinders in the case of engines using superheated, as compared with those using saturated steam. The pistons and piston valves are alike packed with cast iron spring rings, these being necessary to ensure steam tightness at the high pressures; the pistons are of cast iron. These six superheated-steam locomotives have been in use since April 1906, and a coal saving of from 12 1/2 to 20 per cent and a water saving of about 20 per cent is claimed for them. No definite results are as yet to hand, as to the time the locomotives are out of service for repairs, or with regard to annual maintenance costs, but it is claimed for this type of superheater that no special difficulty has been experienced with any particular part, and that no blocking up or wearing out of the superheater tubes has been observed. The essential feature of this design is the comparative ease with wich a single superheater element can be dismantled. The lubricators used are of the sight-feed type.

The Lancashire & Yorkshire Railway have adopted the Schmidt smoke-tube type of superheater, in which the tubes meet the header in a vertical direction. There are 18 sets of superheater tubes 1 3/8 inches diameter, No. 9 I. W. G. (= 0·144 inches), of cold-drawn weldless steel, arranged in the smoke-tubes. These latter are 4 3/4 inches external diameter for the greater part of their length, and No. 7 I. W. G. (= 0·176 inches) in thickness. A description of this type of superheater in unnecessary, in view of the recent publications relating to this subject.

The Lancashire & Yorkshire Railway engines fitted wich superheaters employ Joy valve gear, and are fitted with piston valves. The piston and piston-valve spindle packings (fig. 19) are composed of an alloy of 80 per cent lead and 20 per cent anti-

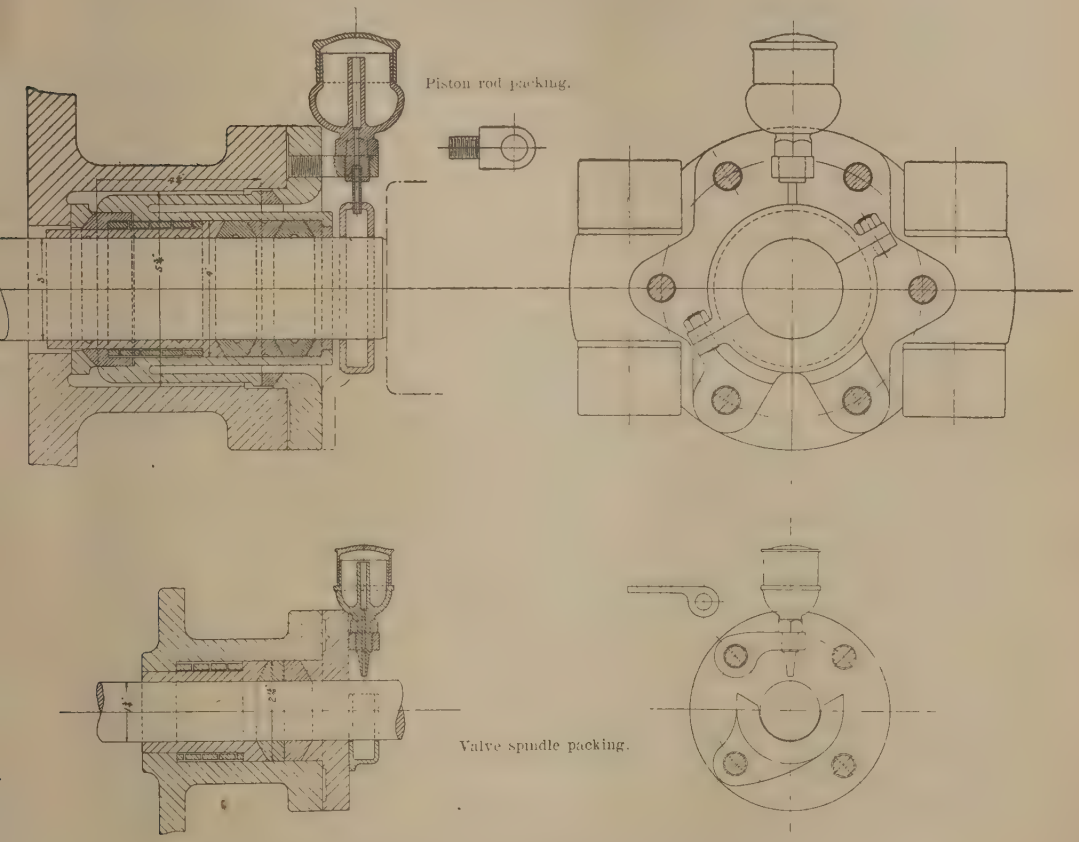


Fig. 19. — Lancashire & Yorkshire Railway. — Metallic packing.

mony, and it will be noticed that excellent facilities are provided for air-cooling; the piston itself is made of cast iron. The two engines at present in use on this Railway have been in service since January 1907, and the results of experiments made for the purpose of determining the effect of superheating, so far as saving in water and coal is concerned, shew an economy of from 15 to 20 per cent. It is further claimed for these engines that their cylinder power is higher, that there is a reduction in the maximum cut-off to 70 per cent, a higher initial total pressure, and that the full

temperature of the steam is utilised to a greater degree of expansion. The maximum superheat is 270° Fahr. and is measured at the steam header by means of a Steinle-Hartung Mercury Thermometer, recording in the cab.

The following is a comparative table shewing the principal dimensions of locomotives with and without superheaters :

	WITH SUPERHEATER.	WITHOUT SUPERHEATER.
Grate area	18·75 square feet.	18·75 square feet.
Heating surface : fire-box	108·189 —	107·68 —
— — tubes	762·57 —	1,022 —
— — superheater . . .	191·13 —	...
Weight of locomotive (light)	96,992 lbs.	92,512 lbs.
Working pressure of boiler	180 lbs. per square inch.	180 lbs. per square inch.
Size of cylinders.	20 inches diameter × 26 inches stroke.	18 inches diameter × 26 inches stroke.

With the superheater engines, a fall of pressure of between 20 and 30 lbs. has been observed between the boiler and the valve-chest, but the steam pressure is higher than when saturated steam is used for the same boiler pressure.

As these locomotives have only been in service since January 1907, it is early as yet to say anything regarding the increased cost for repairs to the superheater engine, but up to the present there has been no such increase. No blocking up or wearing out of the tubes or distortion of the fire-box tube-plate has been observed.

These engines are fitted with a mechanical lubricator, by Ritter of Germany, for cylinder lubrication. The cost of this is £30, and the oil used is a mineral oil containing about 1 per cent of saponifiable matter, having a flashing point of about 550° Fahr. a specific gravity of about 0·90, and a viscosity at 212° Fahr. of 195 seconds by Redwood's viscometer.

A copy of the special instructions, issued on the Lancashire & Yorkshire Railway, for handling engines fitted with the " Schmidt " Superheater, is given in Appendix No. 2.

In the mechanical lubricator shewn in the diagram (fig. 38), oil is forced under pressure to the point where it is required, the pressure being obtained by the action of a hanging rod receiving its motion from one of the axles. Regulation is effected by varying the length of this rod.

With the Schmidt type of superheater as used by the Lancashire & Yorkshire Railway, should the uppermost set of one of the vertical rows of tubes require taking out, the two lower sets must also be removed, so that in this particular the " Swindon " type has a distinct advantage. On the other hand, with the Schmidt

superheater the header does not hang down over the face of the superheater smoke-tubes, and thus these can be more readily cleaned out than in the " Swindon " type, where to get at any tube its respective bolt must be removed. Even with the Schmidt type the accessibility of the large smoke-tubes leaves something to be desired, as the upper rows are obstructed by the superheater tubes passing in front of them to the lower smoke-tubes.

From the above, it will be seen that the application of superheated steam to locomotives is only being practised to a very limited extent in those countries to which the present report applies. Of the four Administrations using superheated steam, one is using the Schmidt smoke-box superheater, two, the Schmidt smoke-tube superheater, and the Great Western Railway, one of their own design of the smoke-tube type, as already described.

Feed water heaters. — None of the Administrations replying employ any special means of heating the feed water, although several employ exhaust injectors which recover some of the heat that otherwise would be lost. The Great Western Railway have, as mentioned by Mr. Churchward in the paper previously referred to [1], endeavoured to overcome the troubles arising from the injection of cold water directly into the boiler, by passing the feed-water through pipes in the steam-space.

The London & South Western Railway have, however, employed a feed water heater. As far as can be gathered, this consists of a well in the bottom of the tender, in which are fixed a number of tubes, into which a certain proportion of the exhaust steam is passed, thus raising the temperature of the whole of the feed water. The latter is fed into the boiler through the front tube-plate by means of a pump, and is directed along the length of the barrel.

C. — Damage to boilers. — Pitting, grooving and corrosion. — Means employed to prevent this damage. — Purification of water. — Disincrustants.

1 to 5. — *Purification of water.*

The following among the Railways replying adopt methods of water-softening :

The New South Wales Government Railways use Desrumaux softeners at two stations; soda and lime are used in softening; the attendant tests the water daily with the soap test, and weekly tests are made by the Company's Analyst. The

[1] *Proc, Inst. Mech. Eng.*, 1906, p. 228.

results are satisfactory, but no details can be given, the experiment not having been of sufficient duration. Barium compounds have not been used. An accidental overdose of soda-ash has sometimes caused leakage, but on returning to the normal quantity the leakage has ceased. Following is an analysis of concentrated water which caused priming :

	Parts per 100,000.
Na (K) Cl [1]	144·0
$Ca Cl_2$	5·0
$Mg Cl_2$	1·6

The Western Australian Government Railways use an Archbutt-Deeley softener, in which the water is treated with caustic soda and lime, and the water is analysed periodically to see that the softening is satisfactory. In softening waters, the hardness of which is mainly due to sulphates, chlorides, and nitrates of calcium and magnesium, precautions are taken to keep the sodium salts in the softened water below 30 grains per gallon (43 parts per 100,000). Barium compounds have never been used, owing to their excessive cost. No excessive leakage has resulted from the use of softened water. No special determination has been made of the amount of sodium salts which, if present in a concentrated boiler-water, will cause priming, but the following is given as the analysis of a water which gave trouble from this cause :

	Parts per 100,000.
Soda ($Na_2 O$)	21·35
Lime (Ca O)	1·80
Magnesia (Mg O)	3·24
Chlorine (Cl)	26·81
Sulphuric anhydride ($S O_3$)	Trace.
Carbon dioxide ($C O_2$) combined	3·53
Total solids at 130° C.	60·47
Alkalinity as calcium carbonate	8·0

The Great Western Railway use the Archbutt-Deeley, Desrumaux, Kennicott, Pulsometer, and Reisert softeners. Lime and soda are the reagents used. In one instance, ferrous sulphate is used for clarifying. The softening is controlled by frequent chemical tests and periodical inspection. In the treatment of waters containing calcium and magnesium sulphates, care is taken to prevent undue excess of sodium salts in the softened water. In one case, out of 18 to 19 degrees [2] of sulphate hardness, only 10 degrees are removed by soda-ash, to avoid excess of sodium salts in the treated water. Barium hydroxide has been used experimentally,

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[1] Chiefly sodium chloride.

[2] 1 degree of hardness is equivalent to 1 grain of calcium carbonate in 1 gallon of water (1 part in 70,000).

with chemically satisfactory results, but the cost of chemicals was seven times as much as when soda-ash and lime were used, and was considered prohibitive. Water-softening has effected a reduction in the cost of re-tubing boilers, and softening the harder waters has very greatly reduced leakage. The amount of sodium salts which causes priming varies with the design of boiler, rate of steaming, and nature of the salts. When sodium carbonate is absent, priming generally commences with from 300 to 350 grains of soluble salts per gallon (430 to 500 parts per 100,000).

The Hull & Barnsley Railway soften water with lime, and make daily tests of the softened water for hardness. As this softener has been in use practically since the opening of the Line, no comparative figures can be given shewing the saving effected by it.

The Lancashire & Yorkshire Railway have two Archbutt-Deeley plants, and one Wollaston-Automatic plant, the working of both types being controlled by testing the treated water regularly. The weekly statements are sent to the chemical laboratory, together with periodical samples, which are analysed to confirm the daily tests. In some cases, a saving of 5 $^1/_2$ *d.* per 1,000 gallons in the cost of water has been thus effected. Over-carbonating the softened water, in one instance, led to corrosion, and this part of the Archbutt-Deeley process was afterwards omitted in this particular case. Priming has been found to commence generally when the soluble salts have reached a concentration of from 230 to 250 grains per gallon (330 to 357 parts per 100,000). In one case, where the water contained much sodium carbonate, priming commenced at 200 grains per gallon (286 parts per 100,000).

The London & North Western Railway soften water with lime, and test the softened water daily.

The Midland Railway use the Archbutt-Deeley process with satisfactory results, lime and soda-ash being the reagents employed. Experiments have been made with barium hydroxide, but the cost has been considered too great. Priming is prevented by limiting the amount of alkali used in softening. 150 grains per gallon (214 parts per 100,000) of mixed sodium salts have been found to cause priming, and with another water containing chiefly sodium chloride, 170 grains per gallon (243 parts per 100,000) caused the same effect. The boiler experimented with in each case was a small standard type of locomotive boiler, with barrel 10 ft. 4 in. long × 4 ft. 2 in. diameter, and fire-box 5 ft. 11 in. long.

The North Eastern Railway use the Desrumaux process, and test the water with soap solution twice a day. Softening the water has considerably reduced the number of tube failures, and has enabled a reduction of about 12 per cent to be made in the boiler repairing staff. It has also effected a saving of about 58 per cent of the original cost of water, which had to be purchased.

The Taff Vale Railway use the Porter-Clark process at one small depôt.

The Southern Mahratta Railway use no softening process, but are about to instal one.

The Cape Government Railways use, in one of their worst districts, two Mirrlees-Watson Yaryan Distillers. One is kept in regular use, and the other is used only in times of drought, when the dams dry up and they have to fall back on bore-hole water. The Distillers are costly to work, and can only be used with economic advantage when the water is very bad. They also have a Kennicott water-softener at one station, which has given satisfactory results.

The Natal Government Railways use a Kennicott softener in their worst district, which has proved beneficial, but which has not been installed long enough to give any figures. Excessive leakage has occurred where the water is bad, but softening the water has had a beneficial effect.

6 and 7. — *Use of disincrustants.*

In answer to these questions, the following replies have been received from those Railways which use, or have used, disincrustants.

The New South Wales Government Railways have used disincrustants of unknown composition, but the results were not satisfactory.

The Western Australian Government Railways have used with success the two following boiler fluids :

	No. 1.	No. 2.
Caustic soda	20	...
Sodium carbonate	...	31·79
Sodium silicate	...	31·55
Arsenious oxide	28	...
Water	52	36·66
	100	100·00

The amount of each fluid required was calculated from the analysis of the water, and this quantity was placed in the engine tank. The fluids were not long enough in use to admit of much data being taken. No excessive leakage resulted from their use.

The Hull and Barnsley Railway have used, with good results, a vegetable boiler fluid containing tannin, known as " D. M. Boiler Enamel ". They have experienced no leakage.

The Lancashire & Yorkshire Railway use a disincrustant which is, essentially, a contracted solution of sodium carbonate containing a small amount of caustic soda, which is found to be satisfactory in nearly all cases. Excessive leakage has not resulted from the use of this disincrustant. The experience of this

Railway goes to prove that leakage of tubes only accurs with water containing calcium sulphate in larger proportion than 5 grains per gallon (7 parts per 100,000). This refers to waters which are not softened, and is due to the calcium sulphate deposited between the tubes against the fire-box blocking up the inter-spaces and causing leakage, probably owing to over-heating of the tubes.

The London, Tilbury & Southend Railway have used disincrustants, but found them of no advantage. Very little leakage has occurred, and this has been stopped by caulking.

The Midland Railway tried aluminate of barium in locomotive boilers for some time at two stations, but it was found to cause serious leakage of tubes and stays, and was therefore discontinued. Quebracho extract was also tried, and was given up for the same reason in running locomotives, but is being used in stationary boilers with good results. The cause of leakage in locomotive boilers is obscure. It seems most likely to be due to the scouring action of the disincrustant, and no effectual means of preventing it has hitherto been discovered.

The Oudh & Rohilkhand Railway use a decoction of eucalyptus leaves and common soda as a disincrustant, and have experienced no trouble from leakage.

The Southern Mahratta Railway have used " Lord's Chemical Boiler Composition " with very good results, the scale being completely removed from tubes and boilers plates, and there was no excessive priming.

The Central South African Railways used a decoction made of gum leaves, which successfully removed scale. In some cases, where heavy scale had formed, " Atlas " and " Globe " fluids have been used. The use of disincrustants is not advocated. When such have been used to remove heavy scale, leaks have developed in consequence of the removal of the scale.

8. — *Cracks, pitting, grooving and general surface corrosion.*

These defects, though each known under different names, are often so closely related to one another as to make it at times difficult to decide under which of the heads some particular defect shall be classed. Particularly is this the case with cracking and grooving. The conditions which result in cracking only, may, if corrosion be also present, result in grooving. Take, for example, the case of the smoke-box tube-plate; some Administrations shew this as developing cracks in the lower half of the plate, but generally the defect in this part is classed under grooving. The difficulty is to distinguish, from the brief descriptions given, whether the Administrations refer to true cracking, or to grooving resulting from the process of gradual cracking, due to severe stresses in flanges, etc., with attendant corrosion. In view of this consideration, it has been though advisable to

adhere rigidly to the replies sent, and such has been done in the table given (No. 3).

It may, however, be stated that the reporters look upon cracking as a fracture, or partial fracture, which is due to the metal becoming ruptured owing to its being unable to withstand the stress put upon it. In some cases, a partial rupture is sufficient to relieve this stress for the time being, with the result that the crack does not become a fracture right through the plate. A groove is primarily due to oxide of iron having formed on a portion of the boiler which is subject to slight movement, due generally to the pressure in the boiler undergoing some alteration, but possibly augmented to some extent by the vibration resulting from ordinary running. This movement causes the scale or rust to crack off, but this is again produced when suitable conditions occur for its formation. The continuation of this action produces a groove. This may not perhaps cover every particular case, but it is probable that grooving is the general result of this action.

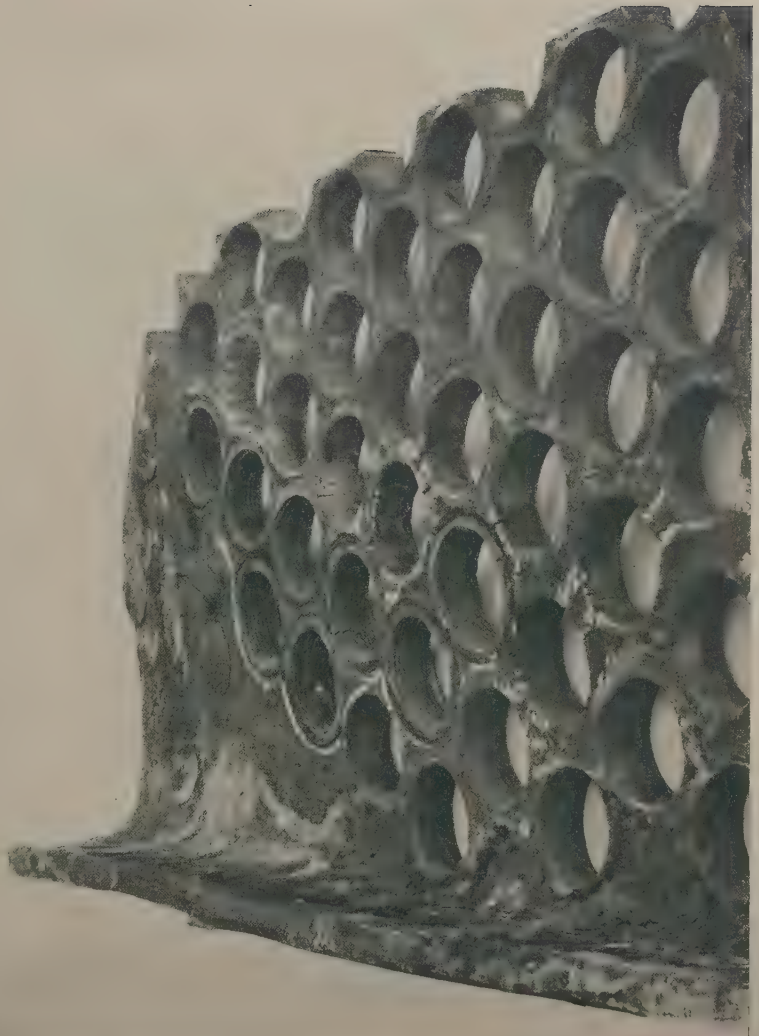
Figure 20 will be found interesting. This shews a portion of a cracked drumhead tube-plate, the crack resulting in complete fracture along the root of the flange. On the exterior radius of the flange on the water side, the grooving is only slight, and the crack seems to have little connection with this. It is in great measure due to these cracks developing, that the drumhead tube-plate has been abandoned by several Administrations in favour of the extension tube-plate.

It will be seen from Table 3, that cracking is principally confined to the region of the fire-box, occurring there in the radii of flanges both of the outer and inner plates. The most common position, however, for the development of cracks is between the tube-holes of the fire-box tube-plate (fig. 21), round the outside of the plate, especially in its upper part, and sometimes, though not so frequently, between the stays on the copper side of the box (fig. 22). It will also be noticed that cracks occur in both types of fire-hole joint, *i. e.* in the ring and flanged joint (fig. 23 shews crack in ring-joint).

In all cases where copper plates are used for fire-boxes, there is a liability to cracking on the inside of any flanged portion. This oftentimes does not result in a single crack, but in a series, which are not usually continuous. An example of this taken from the inside of a copper tube-plate is shewn by figure 24, and similar cracking is liable to occur in the corners of all copper fire-box plates. It is possible that these cracks may be started in an incipient form when the plate is bent, but only develop under continually repeated stresses as the boiler " breathes " in working. They develop in places where slight movement can take place, and do not occur in the stiff portions of the box, as for instance in the top corners of tube-plates. Figure 25 shews an example of a crack in a copper plate due to a different cause, this being a case where the wrapper-plate was built up in three pieces, *i. e.*, two sides and one crown-plate, the latter being rigidly tied by transverse roof-bars. In this case, the cracking has been caused by the excessive stress induced on the line of jointing of the side and crown-plates.

Fig. 13. — Brass tube showing erosion at fire-box end.

Fig. 20. — Cracked drum head tube-plate.



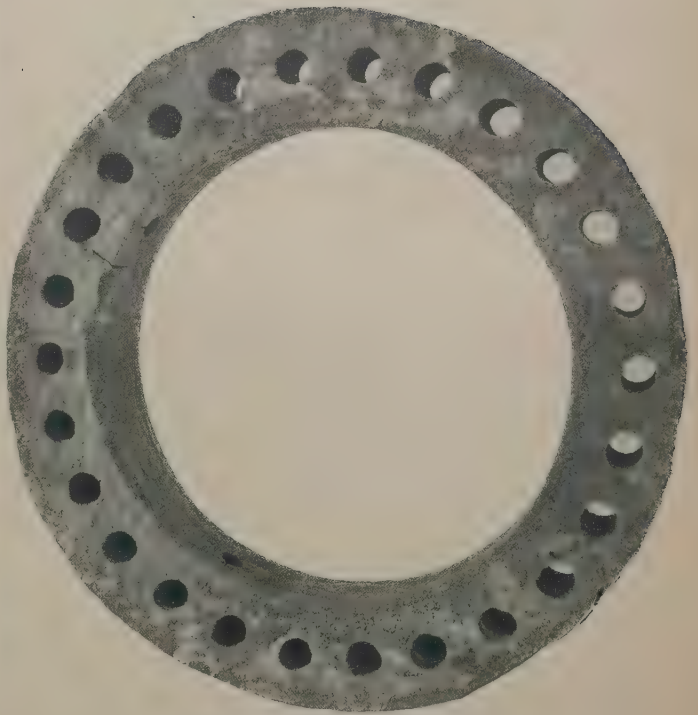


Fig. 23. — Cracking of fire hole ring.

Pitting in the boiler, as apart from the tubes, is in nearly all cases confined to the lower parts of the barrel, while this in some instances is mentioned as being worse at the smoke-box end. The Lancashire & Yorkshire Railway state that the pitting is worst in small boilers where the lowest tubes are close to the bottom of the barrel, and the Natal Government Railways find the same result to be brought about by the use of boilers with shallow fire-boxes. Both these cases may be due to the construction of the boiler not allowing good circulation, with the result that certain corrosive matter may tend to lie at the bottom of the boiler in contact with the plates.

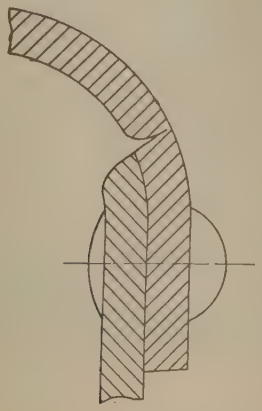


Fig. 25. — Sketch showing cracking in copper fire-box plate, at seam of side and crown plates

It will be seen from the summary, that the four principal points at which grooving takes place are as follows :

1° Bottom of smoke-box tube-plate;
2° Just above foundation ring in outer casing plate, especially near the corners;
3° Bottom of circumferential lap-joints in the interior of the barrel;
4° Throat-plate flanges, near the position where the flange joins the bottom of the boiler barrel.

Photographs of examples of all of these are shewn in figures 26 to 29.

There are several other places at which slight or occasional grooving is found, as for instance near the edge of a fire-hole door ring, and at the flange of those in which the door-hole is formed by flanging the plate. In some cases, grooving occurs on the inside of the vertical flanged portion of the door-plate, and occasionally may be found between vertical rows of stays, in the lower portion of the throat-plate, on the water side. Experiments have been made by two of the

railways with a reversed flange door-plate on the lines of figure 30. This type offers great advantages, as will be readily understood, but unfortunately the plates are liable to groove as shewn.

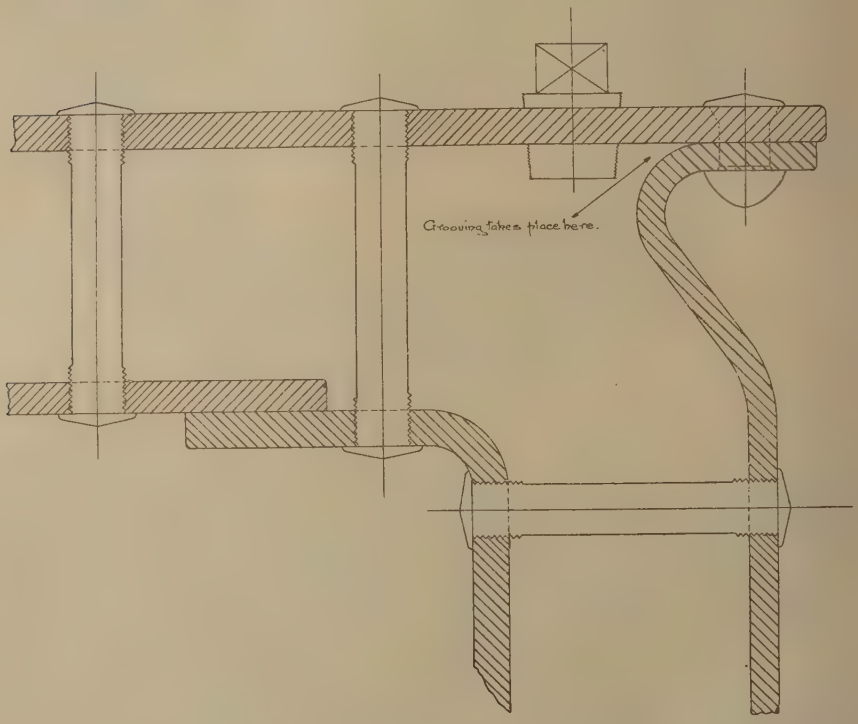


Fig. 30 — Lancashire and Yorkshire Railway. — Reverse flange fire-box back plate.

With regard to general surface corrosion, this is stated as taking place principally over the bottom of the boiler barrel and smoke-box tube-plate. The Eastern Bengal State & East Indian Railways find that these latter plates corrode inside the smoke-box, owing to the corrosive effect of the smoke-box gases, but several administrations, including the Eastern Bengal State Railway, find that these plates also corrode on the water side (fig. 31). The Lancashire & Yorkshire Railway finds that corrosion of the boiler plates takes place near the feed-water delivery. The other corrosion mentioned is that which is general over the whole of the boiler interior.

9. — *Notes and sketches relating to boiler repairs.*

The general practice is to keep a written record only of the repairs carried out to a boiler, but the Western Australian Government Railways and the Southern

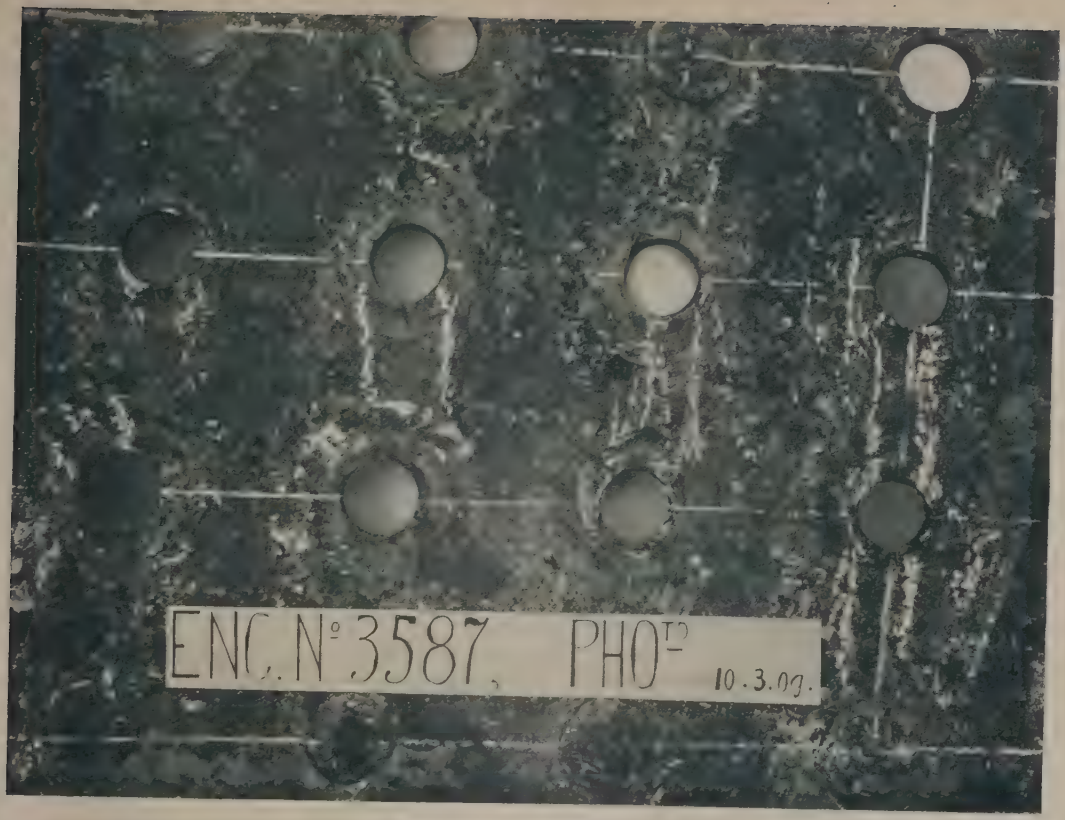


Fig. 22. — Cracks round stay-holes.

Fig. 24. — Cracking in flange of copper fire-box tube-plate.

Fig. 27. — Grooving in steel plate at junction with foundation ring.

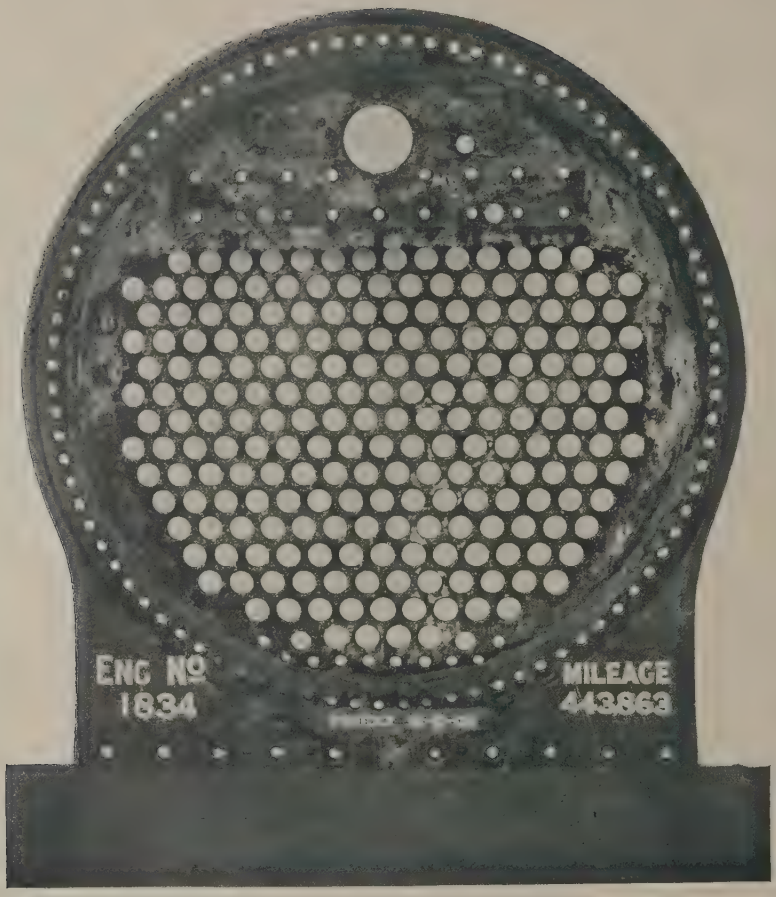


Fig. 26. — Grooving of smoke-box tube-plate.

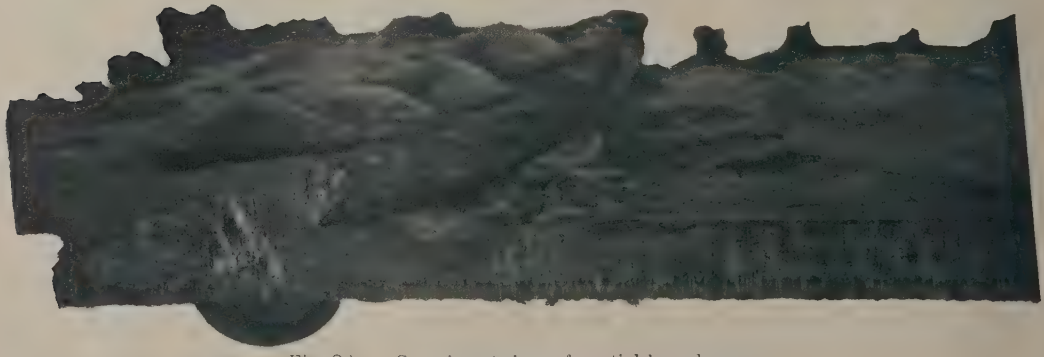


Fig. 23. — Grooving at circumferential barrel seam.

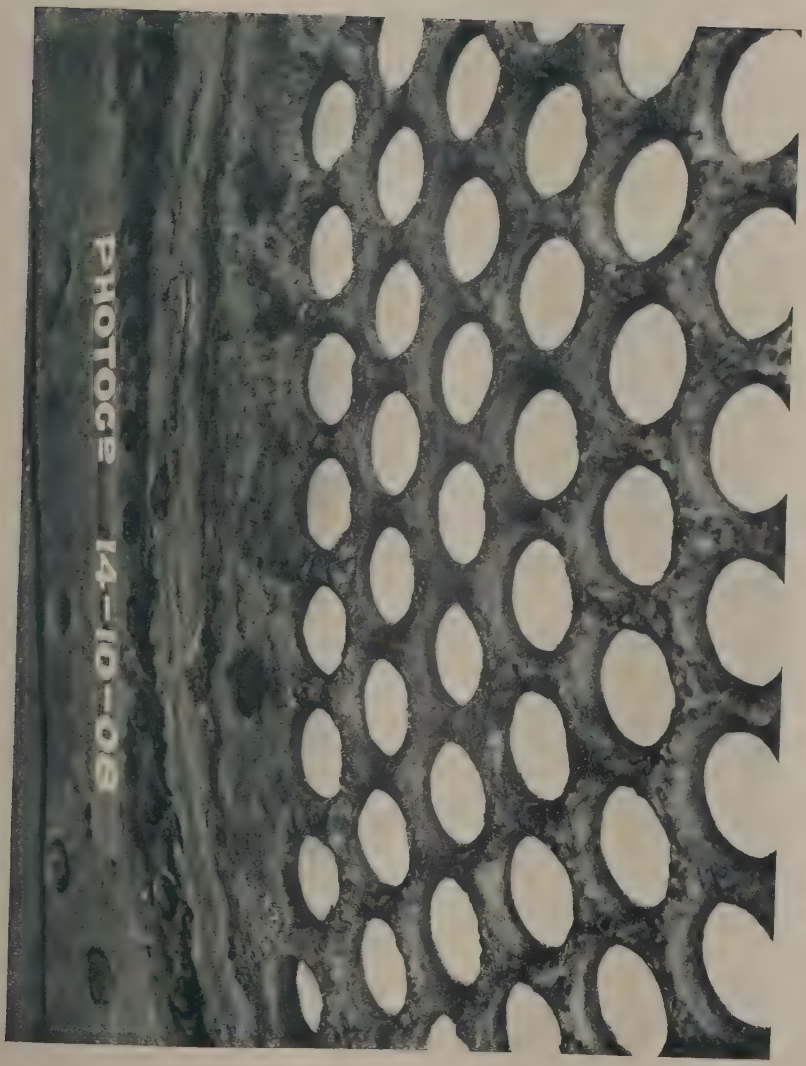


Fig. 31. — Internal corrosion of smoke-box tube-plate.

Fig 29.

Fig. 35. — Cracks in copper stays near copper plate.

Mahratta Railway make sketches indicating the nature of the repair, in addition to the written particulars. A copy of one of these repair sheets from the former railway is given in appendix No. 3.

10. — *Method of construction to prevent cracks, pitting, grooving and corrosion.*

In connection with the summary of replies given, a few points are perhaps worthy of special notice. Several Administrations have expressed the opinion that a more liberal spacing of the tubes near the edges of the tube-plate, and the practice of not allowing the tubes to come into close proximity to the edge of the plate, serve to prevent cracking in the plate flanges, and also between the tube holes, near the flange of the plate. Increase in the radius of the plate corners has also a good effect in preventing both cracking and grooving, as tending to lessen the localisation of bendings actions, causing high stresses in the plate flanges, by distributing these over a larger area.

The copper liner (fig. 32) used by the Great Eastern Railway is stated to serve a useful purpose in preventing grooving near the foundation ring, while the internal angle-iron ring connecting the smoke-box tube-plate to the barrel (fig. 10) is said to have a similar preventive effect against the grooving which so often occurs in this plate. Increase in the water-spaces prevents breaking of stays and also corrosion of the fire-box plates by giving a better circulation of water.

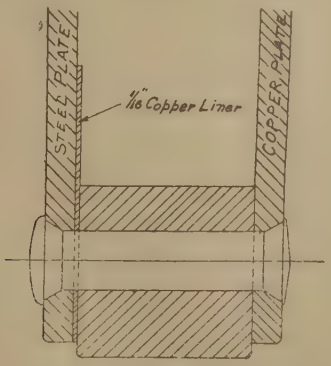


Fig 32. — Great Eastern Railway.
Prevention of grooving at foundation ring by insertion of copper liner.

Steel tubes have been used in some cases, not only because of their lower cost, but also because they help to lessen the corrosion resulting from galvanic action. The Cape Government Railways state that grooving is much more pronounced in boilers fitted with brass tubes than in those fitted with steel tubes.

Some Administrations state that to minimise the tendency toward the above

defects they have had the Hornish (Hulburd) Patent Mechanical Cleaner fitted to their boilers. A description of this is given in appendix No. 4.

In connection with the question relating to " Methods of construction to prevent Cracks, Pitting, Grooving & Corrosion ", both the Lancashire & Yorkshire and the Cape Government Railways state that their present practice is to increase the width of the water-spaces round the fire-box, as a means of preventing these defects. Referring to table 3, column 7, shewing the breadth of the water-spaces in use by the various Administrations, it will be seen that the Cape Government Railways give the most liberal allowance, viz, 4 inches at the bottom to 5 or 6 inches at the top, but it is to be observed that in this case the fire-box is a shallow one placed over the frames. This has resulted in a decrease of the corrosion of the fire-box plates. With the fire-box fixed in between the frames it becomes necessary to decrease the grate area, other things being equal, in order that the water-spaces may be wider, and there is some tendency at present to do this, so as to ensure an efficient circulation in this very important portion of the boiler.

Position of feed-water delivery. — Thirteen of the Administrations admit the feed-water at the middle of the barrel, and eleven of them near the smoke-box tube-plate (table 3, column 8). No question was directly asked regarding the direction given to the inflowing water, but some interesting remarks on this subject regarding recent experiments on the Great Western Railway will be found in Mr Churchward's paper on " Large Loco' Boilers " (1), and also in the subsequent discussion.

11. — *Washing-out of boilers.*

As will be seen from table 4, the majority of the Administrations still use cold water for washing-out, although several have the question of the installation of a hot-water washing-plant under consideration. Of the six Administrations which already have such plants existent, the Great Central, Great Western, and Hull and Barnsley Railways obtain the hot water by passing it through an injector. The Caledonian Railway and the Central South African Railways employ stationary boilers, as do the Western Australian Gorvernment Railways. The latter use an old locomotive boiler, and pump, and have in addition hot water and wash-out wells. One wash-out well receives the water emptied from the boiler itself, and this is used by the pump for the purpose of washing-out, the pressure at the start being low, and rising to 50 lb. per square inch. After the washing-out is completed, the boiler is filled from the hot water well, where the water is kept at 180° Fahr. by the old locomotive boiler, and, a fire being put in the fire-box, the engine is ready for traffic 30 minutes after.

It will be seen from table 4, column 3, that the mean mileages between washings-out on the different Railways vary from 300 to 1,650 miles, depending on

(1) *Proc. Inst. Mech. Eng., 1906,* p. 167.

the quality of water and the conditions of running. In some cases the washing-out is fixed, not on a mileage basis, but on the number of trips run.

The time allowed for cooling down before washing-out varies on the different railways from 3 to 24 hours; about 8 hours appears to be the most general allowance. It will be noticed that on the Lancashire & Yorkshire and Taff Vale Railways, as soon as the steam pressure is sufficiently reduced, cold water is mixed with the hot water in the boiler, by which means a gradual reduction in temperature is effected.

The pressure of water used for washing-out varies on the different railways from 10 to 80 lb. per square inch.

12. — *Blowing-off boilers.*

It will be seen from table 4 that twenty of the twenty-five Administrations replying are using either "blow-off" or scum-cocks. On the Central South African Railways, these cocks are only used in connection with the Hornish (Hulburd) cleaner, and then only in the sheds. It will be noticed that, although a large proportion of the Railways have engines fitted with these cocks, their use is to some extent discountenanced, as for instance on the Oudh & Rohilkhand Railway, where they are now "not much used, as there is danger of them sticking and causing delays, and since pressures have been increased to 160 and 180 lbs. their use has been given up to a greater extent".

The times that elapse between successive "blowings-off" vary considerably, and of course must depend on the quality of water used, but the London Tilbury & Southend Railway make a practice of using their "blow-off cocks once every 500 miles".

The most usual position for the blow-off cocks is immediately above the foundation ring in the throat-plate, on the centre line of the fire-box. The Western Australian Government Railways have their scum-cocks arranged on the fire-hole door-plate, on left of fire-box and 3 inches above the fire-box crown.

13. — *Specially corrosive waters.*

The New South Wales Government Railways send the following analyses of waters which are specially corrosive.

	Newcastle.	*Sydney.*
	Parts per 100,000.	
Lime (Ca O)	4·54	0·34
Magnesia (Mg O)	4·36	0·59
Soda (Na_2 O)	8·02	2·55
Alkalinity (as Ca C O_3)	15·70	1·50
Sulphuric anhydride (S O_3)	1·72	0·46
Nitric anhydride (N_2 O_5)	0·02	0·007
Chlorine (Cl)	10·00	3·11
Carbon dioxide (C O_2) free	8·20	1·70
Total solid matter at 110° C.	35·16	7·99

Cracks, pitting, grooving and corrosion. — Answers to questions VI-C.

TABLE 3.

NAMES OF ADMINISTRATIONS.	Positions of cracks.	Where pitting occurs.	Where grooving occurs.	Where corrosion occurs.	Methods of construction to prevent these defects.	Breadth of water-spaces.		Position of feed-water delivery.
						Bottom.	Top.	
						Inches.	Inches.	
New South Wales Government Railways.	Bridges and flanged bends of copper tube-plate.	Bottom plates of boiler barrel.	Plates immediately above foundation ring, foundation ring itself, and smoke-box tube-plates round junction with barrel.	Inside steel casing, back, throat and crown-plates.	None.	2 1/2	3 1/2	Middle of barrel.
Tasmanian Government Railways.	Bottom half of front tube-plate at root of angleiron ring; corners of throat-plates near junction of barrel-plates: fire box tube-plates at flanges near bottom rows of tubes and along top flange near top rows of tubes.	Bottom plates of boiler barrel.	Bottom of fire-box casing near foundation ring. Corner of throat-plates near barrel plates.	Slight.	...	2 1/16 and 3 1/2	...	Centre line, middle of boiler.
Western Australian Government Railways.	Between tube-holes in fire-box tube-plate. Crown sheets across front rows of stays.	Below feed-water inlet in barrel plates.	Circular seams; top of foundation ring; top of throat-plate corners; around firehole ring and smoke-box tube-plate.	In steam-spaces, smoke-box tube-plate and fire-box shell sides.	Localisation of bending actions reduced by distribution over a large surface. Avoiding lapjoints in longitudinal seams in flat plates of fire-box.	2 1/2	5	2 feet 6 inches from front tube-plate at centre line of boiler.
Caledonian Railway	Throat-plate and between tubes.	Boiler shell bottom.	Grooving seldom occurs.	Almost nil.	...	2 1/2 to 3	...	Front of boiler below centre line.
Furness Railway.	Front tube-plate.	Bottom of barrel.	At edges of lap-joints.	Bottom of barrel.	...	...	3 3/8	Middle of barrel.
Great Central Railway . . .	In saddle of Belpaire throat-plates. Between tubes in copper tube-plates. Between stays in	Lower part of barrel.	Above foundation ring and at barrel seams.	Lower part of barrel.	...	3	...	About middle of barrel.

Great Eastern Railway . . .	...	...	At foundation ring round mud-holes and at tube-plate joints.	...	Copper liner 1/16 inch used at foundation ring joint (fig. 32).	3	...	2 feet 6 inches from tube-plate on centre line of boiler.
Great Western Railway . . .	Almost entirely confined to firebox tube-plate.	Lower part of barrel	Above foundation ring.	Practically none.	...	3 1/2 throughout in latest.	...	Underside of interior of barrel near smoke-box.
Hull & Barnsley Railway . .	In the firebox back shell-plate, down each side of radius where shell-plate is flanged forward to meet wrapper-plate.	Along bottom of barrel.	In firehole shell-plate just above foundation ring, chiefly at corners in smoke-box tube-plates at bottom.	None.	By providing an internal angle-ring connecting smoke-box tube-plate to barrel. More effective staying of back shell-plates to barrel between copper stays and radius to flange.	3	3 1/2	Downward direction midway along barrel.
Lancashire & Yorkshire Railway.	Between stay-holes and between rivet-holes o flanged firehole.	Lower part of barrel at smoke-box end. This is worse in smal boilers where tubes are near boiler-bottom.	Firehole door-plates round firehole. Occasionally in throat plate radius. In reversed-flange fire-boxes. Top corners of tube-plates. Above foundation ring in front and back-plates in boiler seams.	Near feed-water delivery on boiler plates.	Water-spaces made wider, increase of tube spacing, greater space between boiler barrel and tubes.	2 1/2 4 3/10	4 1/2 4 1/2	2 feet from smoke-box tube plate pointing downwards.
London & North Western Railway.	No systematic observations made.			No special methods.		2 1/2 3 1/4	3 5	Middle of barrel.
London Tilbury & Southend Railway.	...	...	Vertical flanges of throat-plate. Foundation ring corners.	...	...	2 7/8	4	Near smoke box tube-plate.
Midland Railway	Cracks occur in fire-hole rings when these are thin. Flanged fire-holes crack round top side of plate and from rivet-hole to rivet-hole on the copper side. Copper tube-plates crack between tube-holes.	Lower part of barrel over a width of 15 inches, sometimes extending halfway up sides. Chiefly due to water and is confined to a few districts.	Round smoke-box tube-plate at bottom, sometimes three parts of distance round. Circular barrel seams at bottom, sometimes working right through the plate. Saddle plate corners used to groove, but only rarely now. Above foundation ring, near corners, in steel plates.	Practically none. Steel rivet-heads round seams of copper tube-plate corrode away with some waters very rapidly.	Drumhead tube-plate being gradually abolished. Boiler barrel has two plates instead of three. Foundation ring corners of larger radius. Flanged fire holes discontinued in favour of solid rings. Spaces between tubes on sides and top increased.	3	4 to 5	Middle of barrel in old engines, but more recently close to the iron tube-plate.

Cracks, pitting, grooving and corrosion. — Answers to questions VI-C. (Continued.) TABLE 3.

NAMES OF ADMINISTRATIONS.	Positions of cracks.	Where pitting occurs.	Where grooving occurs.	Where corrosion occurs.	Methods of construction to prevent these defects.	Breadth of water-spaces.		Position of feed-water delivery.
						Bottom.	Top.	
						Inches.	Inches.	
North Eastern Railway . . .	None.	Lower part of barrel, and occasionally up to water-line level.	Top of foundation ring and bottom of front tube-plate.	Principally boiler barrel.	Boiler barrels have butt-joints with hoops round, thus giving equal expansion. This type prevents grooving at circumferential seams.	3	4 1/2	Middle of barrel above tubes.
South Eastern & Chatham Railway.	...	Bottom of barrel towards front.	Top of foundation and firehole rings.	...	...	3 2 1/2	6 1/8 4 1/2	2 feet from smoke-box tube-plate.
Taff Vale Railway.	Copper tube-plate.	Boiler barrel and throat-plate below the water-level.	Smoke-box tube plate below the water-line and following the barrel-plates.	Inappreciable.	No special methods.	2 1/2	4 1/2	One fourth distance along barrel from front tube-plate and 8 inches below normal water-level.
Eastern Bengal State Railway .	Radius of flange of back casing and throat-plates. Radius of top flange of copper tube-plates. Hole to hole of fire-box tube-plates, usually in those furthest from the centre tube.	...	Lower part o smoke-box tube-plate near angle-iron at bottom Along fire-box casing plates near foundation ring. Along outer plates of lap-joints near edge of inner-plate.	Generally over the inside of smoke-box tube-plate and als over the lower part exposed to smoke-box gases.	Hornish Patent Mechanical Boiler Cleaner has been fitted to a few engines.	3	5 1/4 (front of box).	Middle of barrel.
East Indian Railway	Angles of fire-box.	Bottom of barrel and bottom of smoke-box tube-plate.	Smoke-box tube-plate.	Smoke-box side of smoke-box tube-plate.	Cracking is lessened by increasing the radius of plate-corners and keeping stays and tubes further back. To prevent general surface corrosion on the lower portion of the smoke-box side of the smoke-box tube-plate, a cast iron protection platei used.	2 1/2	4 1/2.	Middle of barrel.

Great Indian Peninsula Railway.	...	Bottom of boiler barrel up to centre line.	At joints of plates. Bottom of tube-plate. Junction with foundation ring, this and throat-plate in particular.	Smoke-box tube-plate, around holes.	Steel tubes to prevent galvanic action. Causes of defects thought to be structural.	2 1/2 3	4 1/2 5 1/2	One half to three quarters distance along barrel from fire-box end, at side of tubes.
North Western State Railway of India.	Outer casing-plates crack in front and back corners.	Bottom plates of boiler barrel.	At seams in boiler throat-plate and foundation ring.	Bottom of boiler barrel.	...	3	...	Middle of boiler barrel, well below water level.
Oudh & Rohilkhand Railway .	Bend of flanges of tube-plate.	Barrel plates.	Bottom of smoke-box tube-plate.	Top, back and sides of fire-box casing.	Bringing barrel-plates close to tube-plate, which certainly prevents grooving of the tube-plate.	3	4 1/2	...
Southern Mahratta Railway. .	Between holes in copper tube-plate, and in edges of rivet holes of firehole ring seam; back plate of fire-box.	Bottom of boiler barrel and bottom half of throat-plate.	Transverse seams of boiler barrel-plates; sides and bottom of throat-plate next foundation rings and back shoulders of back-plate of fire-box casing.	Boiler barrel-plates, smoke-box tube-plates, and more so with steel plates than with iron.	Abolition of palm stays at bottom of barrel gives good results and ensures longer life to tube-plates.	2	3	Centre of barrel.
Cape Government Railways . .	...	Too erratic to say anything definite.	Smoke-box tube-plates below the water-level at throat-plate flange. Much more pronounced in boilers fitted with mild steel tubes. Apart from tube-plates we are not troubled with grooving.	...	Increase in water-spaces reduces breakage of side stays of fire-box and risk of water space getting choked with scale and mud. The inner fire-box plates are lasting better than with narrower water-spaces, owing to freer circulation of water.	4 3 1/4	5 & 6 5	Middle of barrel.
Central South African Railways	Between tube-holes in fire-box tube-plates, down sides and along bottom. Top and side flanges of this tube-plate. In one class, cracks occur in lower half of smokebox tube-plate.	Circumferential joints and bottom of barrel.	Centre circumferential joint of barrel. Fire-box casing above foundation ring near throat-plate.	No trouble.	Tube-plates made thicker. Pitting and grooving obviated by fitting liner-plates.	3 3 1/2	4 1/2	Centre line of barrel ring, next to smoke box.
Natal Government Railways. .	Between tubes in tube-plate.	Bottom of boiler barrel in boilers with shallow fire-boxes.	...	...	To increase life of fire-box tube-plate when bridges are found to be cracked the holes are bushed and the tube-ends reduced accordingly.	2 1/2 3	4 1/2	Below centre line of boiler, near dome.

Washing-out of boilers. — Answers to questions VI-C.

TABLE 4.

NAMES OF ADMINISTRATIONS.	Are boilers washed out with hot or cold water?	Mean mileages between washings-out.	Time allowed for cooling.	Is "blowing-off" resorted to?	Position of "blow-off" cock.
New South Wales Government Railways.	Cold.	500.	8 hours after blowing-off steam.	Yes. As often as the state of the boiler demands. At some stations before going out each trip.	Generally above foundation ring in throat-plate.
Tasmanian Government Railways.	Cold.	750.	24 hours.	No. Scum-cocks are used. Water is changed once or twice per week when necessary to avoid priming.	...
Western Australian Government Railways.	Hot. Cold water is only used when boiler requires repairs.	300 to 500 depending on district.	12 to 18 hours according to size.	Yes. At pressures below 40 lbs. per square inch. The loco. is stabled with a full glass of water, and before going into trafic, water is blown out at from 10 to 40 lbs. to 1/4 glass level. A scum-cock is also used.	Bottom of throat-plate. Scum-cock is placed on face plate on left of fire-box and 3 inches above fire-box crown.
Caledonian Railway	Hot water generally.	...	...	No.	...
Furness Railway.	Cold.	Not based on mileage, seven days allowed.	7 hours.	No.	...
Great Central Railway	Cold water when time permits, otherwise hot water.	...	8 hours.	Yes. Done when necessary, depending on water used.	Under side of barrel near fire box end.
Great Eastern Railway	Cold water. (On ce week.)	750. No account is taken of quality of water but water is changed if engine is reported as priming badly.	Washed out as soon as pressure is low enough to open mud-doors and plugs.	Yes. Not a general practice but occasionally resorted to, to prevent priming.	Right-hand side of steel wrapper-plate above foundation ring, and near to saddle-plate.
Great Western Railway . . .	Hot and cold water. Hot water is used at some of the larger stations and its use is being extended.	800 to 1,000 according to quality of water used.	Not less than 5 hours.	Yes. But not general practice to rely on it.	...
Hull & Barnsley Railway . . .	Hot and cold water.	500 to 700 according to water used.	6 hours.	No.	...

	gement is being made for washing-out with hot.		as soon as steam pressure has gone down, the cold water being thus mixed with the hot, and a gradual reduction in temperature effected.		
London & North Western Railway.	Cold.	Large express passenger engines : 300, other engines, 500.	No fixed time.	Occasionally in new boilers, but not regular practice.	Back plate of fire-box above foundation ring, and actuated by handle from foot-plate.
London, Tilbury & Southend Railway.	Cold.	1,000.	6 hours.	Yes. After engines have run 500 miles.	Centre line of fire box, immediately above foundation ring in saddle-plate.
Midland Railway.	Cold. Hot under consideration.	Washing-out not based on mileage, but on number of trips, varying with nature of work done and quality of water used.	Not less than three hours.	No.	...
North Eastern Railway. . . .	Cold.	768, Express passenger. 764, Mineral. Express passenger washed out twice per week, and mineral engine boilers once.	One night if possible.	Yes. But not generally in use. A few engines fitted with Hornish Cleaner have a scum-cock to prevent priming. The cleaner is blown-off before leaving the shed and again on return. Scum-cocks are used on heavy gradients.	...
South Eastern & Chatham Railway.	Cold.	No fixed mileage. Depends on quality of water.	...	Yes.	Near middle of left-hand side of fire-box immediately above foundation ring.
Taff Vale Railway	Cold.	700 (about). Quality of water is taken into consideration.	6 hours. After steam is blown off, the cooling is assisted by filling the boiler up with cold water before running out the hot water.	Yes. Only occasionally, and then over a pit when there is trouble from priming.	Centre line of fire-box, immediately above foundation ring in saddle-plate.
Eastern Bengal State Railway. .	Cold	500.	About 10 hours.	Yes. When engine leaves shed, no regular interval.	1 ft. 6 in. from smoke-box tube-plate on bottom of barrel and led in pipe to under side of leading buffer-beam.
East Indian Railway.	Cold.	400, Goods. 600, Passenger (express).	8 hours.	Yes. Only with engines fitted with Hornish Patent Boiler Cleaner.	Centre-line of fire-box immediately above foundation ring in saddle-plate.

Washing-out of boilers. — Answers to questions VI-C. (Continued.) TABLE 4.

NAMES OF ADMINISTRATIONS.	Are boilers washed out with hot or cold water?	Mean mileages between washings-out.	Time allowed for cooling.	Is "blowing-off" resorted to?	Position of "blow-off" cock.
Great Indian Peninsula Railway.	Cold.	300 to 500 in hot weather. 1,000 miles in colder weather with good water.	Not less than 12 hours.	In special cases this is allowed under supervision of shed Foreman, but only when over a pit. Drivers doing this when running are severely dealt with. A scum-cock is used.	On throat-plate near bottom-ring.
North Western Railway (India).	Cold.	400.	8 to 10 hours.	Yes. Where water is unfavourable, these are frequently used for changing water twice in 100 miles.	...
Oudh & Rohilkhand Railway . .	Cold.	500.	8 hours at least.	Yes. Not much used as there is danger of them sticking and causing delays; since pressures have been increased to 160 and 180 lbs., their use has been given up to at great extent.	...
Southern Mahratta Railway . .	Cold.	400 to 800 miles according to quality of water.	12 hours.	Yes. When water is bad. This is done on road as required and also on completion of journey.	Bottom of fire-box above foundation ring in throat-plate.
Cape Government Railways . .	Cold. Hot at one place only where the water is very bad.	500 to 1,000 miles according to quality of water.	4 hours is minimum.	Yes. Use varies with quality of water, and is generally discouraged. Only regularly used in bad water districts.	Bottom of fire-box above foundation ring in throat-plate.
Central South African Railways .	Cold. Hot at one place only.	1,650, dependent on quality of water used.	10 to 24 hours.	No. On account of the noise, delays and dirty state rolling stock gets into under this practice. The Hornish Cleaner is used and serves the function of a scum-cock., it is only used in the sheds.	...
Natal Government Railways . .	Cold.	325 before use of Kennicott softener, now 850. Depends on quality of water, which has more sediment in suspension in rainy season.	Varies with pressure of steam in boiler on arrival in shed.	Yes. Occasionally, depending on quality of water.	Centre line of fire-box immediately above foundation ring in saddle-plate.

The Western Australian Government Railways send the following analysis of a water which was found to cause corrosion unless treated.

	Parts per 100,000.
Lime (Ca O)	1·0
Magnesia (Mg O)	1·54
Soda (Na_2 O)	10·3
Alkalinity (as Ca C O_3)	1·3
Sulphuric anhydride (S O_3)	0·75
Chlorine (Cl)	11.71
Carbonic anhydride (C O_2) combined	0·54
Total solid matter	32·43

The Great Western Railway have a very few soft upland surface waters, containing less than 4 grains per gallon of calcium and magnesium salts, which are specially corrosive.

The Hull & Barnsley Railway send the following analysis of a specially corrosive water :

	Parts per 100,000.
Lime (Ca O)	5·00
Magnesia (Mg O)	6·91
Iron oxide and alumina (Fe_2 O_3 and Al_2 O_3)	0·50
Silica (Si O_2)	2·40
Sulphuric anhydride (S O_3)	29·81
Chlorine (Cl)	7·80
Alkalinity (as Ca C O_3)	23·00
Total solid matter	57·24

The Lancashire & Yorkshire Railway have experienced some corrosion with certain moorland waters almost free from scale-forming matter. The use of boilers already covered with a film of scale has been found to stop the corrosion.

The London & North Western Railway have no specially corrosive waters. They state that in districts where the water is of a corrosive character, its effects are largely neutralized by the use of other non-corrosive waters which are taken during a trip.

The Midland Railway send the following analysis of a water obtained from a tunnel in the Millstone Grit and associated shales which is exceptionally corrosive to boiler barrels :

	Parts per 100,000.
Lime (Ca O)	6·04
Magnesia (Mg O)	3·66
Alkalinity (as Ca C O_3)	17·54
Sulphuric anhydride (S O_3)	5·66
Nitric anhydride (N_2 O_5)	0·08
Chlorine (Cl)	1·03
Carbon dioxide (C O_2), free	0·74
Dissolved oxygen	0·94
Total solid matter at 130° C.	30·4

This water causes general corrosion of the boiler barrel-plates below the water line, and of the wrought iron longitudinal stays, attacking especially the rivet-heads round the fire-box seams. It forms a soft scale which it not protective.

The North Eastern Railway give the following analysis of a water which is very corrosive to boilers and has a distinct acid reaction :

	Parts per 100,000.
Lime (Ca O)	1·90
Magnesia (Mg O)	0·93
Soda (Na_2 O)	Nil.
Alkalinity (as Ca C O_3)	Nil.
Sulphuric anhydride (S O_3)	3·00
Chlorine (Cl)	1·00
Total solid matter at 130° C.	7·60

The Great Indian Peninsula Railway send the following analyses of waters taken from eight stations on their most important district, where most damage has been done by the pitting of boilers :

—	*Bombay Tansa.*	*Bombay Vehar.*	*Kalyan Waldhani nullah.*	*Kalyan up well.*	*Kalyan station well.*	*Vasind.*	*Kasara.*	*Karjat.*
	Parts per 100,000.							
Lime (Ca O)	2·571	2·857	6·143	10·714	14·000	3·571	2·571	2·857
Magnesia (Mg O)	Traces.	Traces.	2·059	0·617	0·617	Traces.	Traces.	Traces.
Iron and Alumina (Fe_2 O_3 and Al_2 O_3)	Traces.	Traces.	Traces.	Traces.	Traces.	Traces.	Traces.	0·714
Silica (Si O_2)	2·286	0·571	3·857	3·571	4·000	2·857	1·143	1·857
Sulphuric Anhydride (S O_3)	Nil.	Nil.	Nil.	Traces.	Traces.	Nil.	Traces.	Nil.
Chlorine (Cl)	1·000	1·200	2·000	6·000	6·000	1·000	1·000	1·000
Carbonic Anhydride (C O_2)	10·000	7·143	12·857	61·143	54·000	15·714	9·142	14·286
Volatile and organic matter	1·714	2·857	4·000	21·714	15·714	0·857	1·571	1·857

The Southern Mahratta Railway give the following analysis :

	Parts per 100,000.
Calcium carbonate	0·79
Magnesium carbonate	16·24
Sodium carbonate	83·12
Calcium sulphate	14·66
Sodium chloride	34·45
Silica	6·16
Alumina	3·68
Iron	Traces.
Carbonic acid (free)	14·24
Hydrogen sulphide	0·43

	Parts per 100,000.
Organic matter	8·20
Total incrusting solids	41·53
Total non-incrusting solids	117·57

14. — *Prevention of corrosion by Portland cement, paint, or by special treatment of water.*

Of the Administrations replying to these questions, six have tried or are about to try the effect of painting or otherwise coating the interior of their boilers with Portland cement, with a view to the prevention of corrosion and pitting. One line finds that the cement washes off, but three of the others, all in Australasia, state that the results obtained are satisfactory.

Although three Administrations state that they paint the insides of their boilers with other material, there is no uniformity in the kind of material used, in fact none of them use the same constitutents, and in only one case, that of the Southern Mahratta Railway, has it been stated that definitely good results have occurred.

Few replies are given as to special treatment of water, but the Great Western Railway state that from $^1/_4$ to $^1/_2$ lb. of slaked lime per 1,000 gallons of feed-water is added to the water tank in a few instances, where exceptionally soft water is used exclusively. The Midland Railway have experimented with the water referred to in the reply to question 13, by softening with lime and adding to the softened water about 4 parts of caustic lime per 100,000 in excess. This treatment greatly reduces the amount of pitting and corrosion, but does not entirely prevent it. Where the water does not contain enough lime, the Cape Government Railways add a little, so as to get a thin coating on steel and iron tubes, to reduce the tendency to pit.

15. — *Use of zinc plates.*

The use of zinc plates, once looked upon as a specific for pitting, seems to be in disfavour, as although five lines state that they have tried them, they have abandoned their use, whilst the Central South African Railways are proposing to fill their washout plugs with zinc, with the hope of preventing corrosion round the plug holes, but the results are so far indefinite. A summary of the replies on these points is given in table 5.

16. — *Fire-box stays and their protection.*

It will be seen from table 6 that in the case of the Administrations coming within the scope of this report, copper is still the principal material used for fire-box stays.

With regard to the benefits to be derived from the use of bronze stays, there is considerable divergence of opinion. Some Administrations are using bronze stays

Answers to questions VI-C, 14 and 15. TABLE 5.

ADMINISTRATIONS.	Portland cement.	Paint, etc.	Zinc plates.
New South Wales Government Railways.	Used with satisfactory results so far.	...	Tried, but not found economical.
Tasmanian Government Railways.	Used with coal-tar and applied hot.	...	...
Western Australian Government Railways.	Used on repaired boilers, mixed to consistency of thick paint, with good results.	...	...
Great Western Railway	...	...	Tried experimentally; results did not warrant adoption.
Lancashire & Yorkshire Railway .	Have tried cement, but find it washes off.	Are trying a special paint; results not yet known.	...
South Eastern & Chatham Railway.	...	Use red oxide.	...
East Indian Railway	Is used.	...	...
Great Indian Peninsula Railway .	Using experimentally as Bengal Nagpur Railway have had successful results with it.	Have been using boiled oil and graphite, but find it percolates through seams and to some extent discontinued.	...
Oudh & Rohilkhand Railway . .	...	...	Tried, but not successful.
Southern Mahratta Railway . . .	...	Tar and graphite internally, and « Siderosthen» paint externally with good results.	Tried, with indifferent results.
Central South African Railways .	...	...	Are trying wash-out plugs filled with zinc. Results indefinte, but practice inexpensive.

only, and the Tasmanian Government Railways claim for them a longer life than for those made of copper. The Western Australian Government Railways say " Two " kinds of bronze stays have been used, but the composition is not known, as we " have made no analysis. One was a very yellow metal (1), and the other much the " colour of copper (2). The yellow bronze stay started to decompose after being " twelve months in use, and in two years had wasted away from $^{15}/_{16}$ inch diameter " to $^{1}/_{2}$ inch diameter. Decomposition took place on the water side of the fire-box " plate, and extended to about $^{5}/_{8}$ inch from the plate. The other bronze remained " good in the water-space, so far as decomposition was concerned, but fatigue set " up and the stays broke on the shell end, and sometimes close to the fire-box " plate. These stays are being rapidly removed and replaced with best soft copper " which gives good results ".

The London & North Western Railway, it will be observed, tried aluminium bronze, but as the results were far from being satisfactory its use has been discontinued (3).

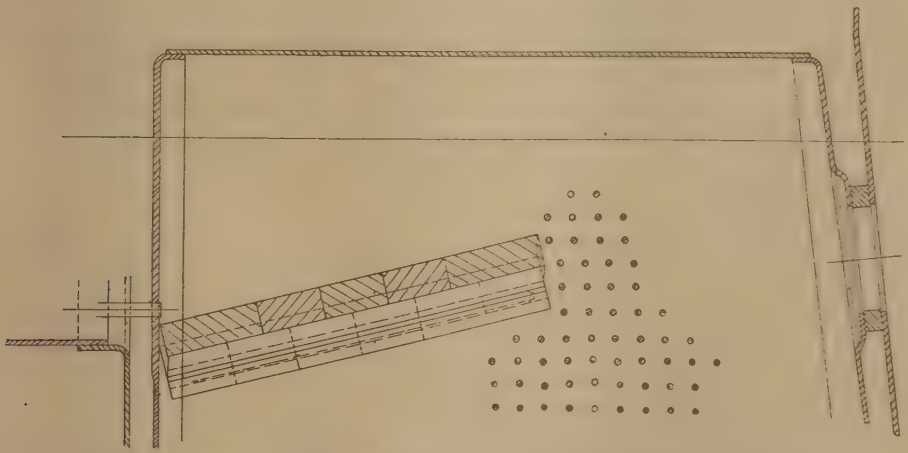


Fig. 33. — Diagram showing area of fire-box stays most affected by flames round arch.

One of the troubles with bronze stays is that the heads drop off in the fire-box much more readily than they do with copper. An explanation of this defect may be found in the fact that under the pressure in the water-space the copper plates of

(1) *Note by Reporters.* — Probably a copper-zinc alloy containing, approximately, 60 per cent copper and 40 per cent zinc, with very small quantities of iron, manganese and nickel.

(2) *Note by Reporters.* — Probably an alloy of copper with about 3 per cent nickel and 1·5 per cent iron.

(3) F. W. Webb, " On locomotive fire-box stays " (*Proc. Inst. Civ. Eng.*, vol. 150, 1902, p. 87).

Fire-box stays and their protection. — Answers to question VI-C (16).

TABLE 6.

NAMES OF ADMINISTRATIONS.	Metal or alloy used, and composition of alloy.	Advantages derived from using other material than copper.	Position of fracture of stay: *a*) in itself; *b*) in fire-box.	Are flexible stays used?	Do stayheads burn off? What means are taken to prevent this?
Tasmanian Government Railways.	Copper and Stone's bronze.	Stone's bronze gives a longer life of stays than coper.	*a*) Near outside of fire-box casing. *b*) Near throat-plate.	None used.	...
Western Australian Government Railways.	Copper. Flexible stays of bronze has been tried in over 100 boilers, but proved to be a complete failure and use was discontinued.	See reply to	question 16.	...	The heads of the bronze stays drop off, sometimes flush with the fire-box plate, but more frequently about 2 or 3 threads in the hole.
Caledonian Railway	Stone's bronze and Melloid.	Fewer breakages and longer life.	*b*) First three rows from tube-plate and back-plate, and first five rows from crown.	No.	Great care is taken with riveting of heads.
Furness Railway	Copper and bronze.	...	*b*) In top rows near casing-plate.	Flexible stays are being tried.	Bronze stay heads burn away in fireway, now being replaced by copper.
Great Central Railway	Copper and Stone's bronze.	...	*b*) The upper rows of the stays in the fire-box sides are those most liable to fracture.	...	No. But they gradually burn away.
Great Eastern Railway	Stone's bronze.	...	*a*) Close to the steel plate. *b*) In top row of wrapper and back-plates, also in corner stays of top row in throat-plate.	Yes. Saw cut stays.	...
Great Western Railway. . . .	Copper, Melloid, Stone's bronze and iron. Copper is now in general use.	...	*a*) Just inside wrapper-plate, and in case of heads falling off just inside copper plate. *b*) At side near back-plate	...	The heads do fall off, but the best remedy is increased water-space.

Hull & Barnsley Railway . . .	Copper.	...	*a*) Close inside steel plate.	...	A few stay heads drop off, but they burn away and give trouble. We find that increasing stay head does not materially increase the life of a stay.
Lancashire & Yorkshire Railway.	Copper, containing not less than 0·35 per cent and not more than 0·55 per cent of arsenic. Bismuth not exceeding 0·005 per cent, and other foreign elements exclusive of combined oxygen not to exceed 0·25 per cent.	...	See figure 34.	No	Additonal washout plugs give reduction of this trouble.
London & North Western Railway.	Copper. Aluminium bronze has been tried, but the results were far from satisfactory and it was given up.	...	*b*) Along top rows in back-plate and along side-plates about the level of the fire.	...	Yes. About the fire-level. No special means adopted, though some have been tried.
London Tilbury & Southern Railway.	Copper-best soft rolled.	...	*a*) Near the casing-plate. *b*) Generally in the upper rows near the back-plate.	No.	Stay heards are burnt away in the ordinary course of wear, but are removed before any signs of the heads dropping off is observable.
Midland Railway.	Copper containing 0·3 to 0·5 per cent of arsenic, not more than 0·1 per cent of lead, and not less than 99·2 per cent of metallic copper. Stone's No. 7 bronze in new high pressure boilers, containing approximately: Copper, 95·5 per cent; Nickel, 2·9 per cent; Iron, 1·6 per cent; with traces of manganese and silicon.	...	*a*) Generally close to steel shell though a few fracture close to the copper plate in the water space. *b*) Top, front and back corners, mostly in front. In vicinity of brick arch at end of carrying brackets; also close to vertical flanges. The palmstays often break; but since iron lugs were lengthened, not so frequently al formerly. The copper stay used for securing these palmstays has been replaced by an iron one, and since this was done there have been no broken stays. Copper stays do not break so often since their diameter was increased from $^{7}/_{8}$ inch to 1 inch and 1 $^{1}/_{8}$ inches in outside rows.	Yes. Saw-cut bronze stays.	Yes. Those in position shewn in figure 33 are most affected : in heavily worked engines they burn away rapidly. Protective devices are being tried.

Fire-box stays and their protection. — Answers to question VI-C (16). (Continued.) TABLE 6.

NAMES OF ADMINISTRATIONS.	Metal or alloy used, and composition of alloy.	Advantages derived from using other material than copper.	Position of fracture of stays: *a*) in itself; *b*) in fire-box.	Are flexible stays used?	Do stayheads burn off? What means are taken to prevent this?
North Eastern Railway. . . .	Principally copper.	No advantages from use of other alloys.	*a*) Near steel casing-plate mostly. *b*) Top row in black-plate and top row of throat-plate in boiler barrel, and the first row from the flange of the tube-plate 5th or 6th from top, each side.	Stone's bronze flexible stays used to a slight extent.	All fire-box stay heads burn away in the fire-space.
South Eastern & Chatham Railway.	Stone's bronze flexible stays.	...	No trouble.	Stone's bronze flexible stays.	...
Taff Vale Railway	Copper, iron and steel.	...	*a*) No particular position. *b*) Usually in the tube-plate pocket.	No.	No.
Eastern Bengal State Railway. .	Copper and bronze	No advantage from bronze stays. Heads drop off in fire-box.	*a*) Near casing-plate from below upwards, and when near fire box-plate, from above downwards. *b*) Near top and front of the fire-box side-plates.	...	Yes.
East Indian Railway.	Copper. Stone's bronze stays have also been tried, but are being discontinued as the advantage is not apparent.	No advantage from Stone's bronze stays.	*b*) At side seams, and along the top row where most movement may be expected.	Yes. Stone's flexible bronze stays have been tried with no appreciable advantage.	...
Great Indian Peninsula Railway .	Copper.	...	*b*) At top of fire-box where stays are longest.	...	Heads burn away, but do not fall off.

North Western Railway (India.).	Copper. Stone's bronze stays have been tried.	...	*a*) At centre and towards the copper plates. *b*) Both top rows and top corners of back of fire-box, also at sides where the brick-arch rests.	...	Yes. But not frequently. This is due to the water-ways getting choked up and the copper plates bulging through becoming overheated.
Oudh & Rohilkhand Railway . .	Stone's bronze stays have been used with good results. Lowmoor iron has been used; they never break, but rust away rather quickly. Copper generally used now.	...	*a*) Clost to iron plate. *b*) Two top rows at sides —we have much trouble with broken stays in these parts.	...	We are much troubled with stay heads and rivet heads (of copper) dropping off in certain classes of boilers, and there is nothing to account for it. It is generally worse in new boilers and the ones put in to replace the broken ones seldom give trouble.
Southern Mahratta Railway . .	Copper. This is used chiefly and has proved most satisfactory. Stone's bronze stays have also been used, but have not proved reliable generally breaking off close to the fire-box casing plates and close to the palm-stay brackets.	...	*b*) Near shoulders of fire-box, the two rows next the fire-box tube-plate and top corners of fire-box back-plate.	No.	No special trouble.
Cape Government Railways . .	Copper and iron. Copper in copper fire-boxes and best stay-bolt iron in steel fire-boxes.	...	...	...	The increase in width of the water-space has reduced the burning away of the stay heads. Not much trouble in this connection when rivetting is good.
Central South African Railways .	Muntz Metal Company's special nickel copper M. N. 2 alloy, Stone's bronze and copper.	...	*a*) Just inside the wrapper-plate. *b*) Front of fire-box just at the back of the tube-plate. Also in throat-plate, generally due to breakage of palm-stays.	Yes. Muntz metal Company's M. N. 2 alloy and stone's bronze.	...
Natal Government Railways . .	Stone's special bronze.	Stone's special bronze gives little trouble from breakages and is generally satisfactory.	...	...	Practically no trouble from heads burning off.

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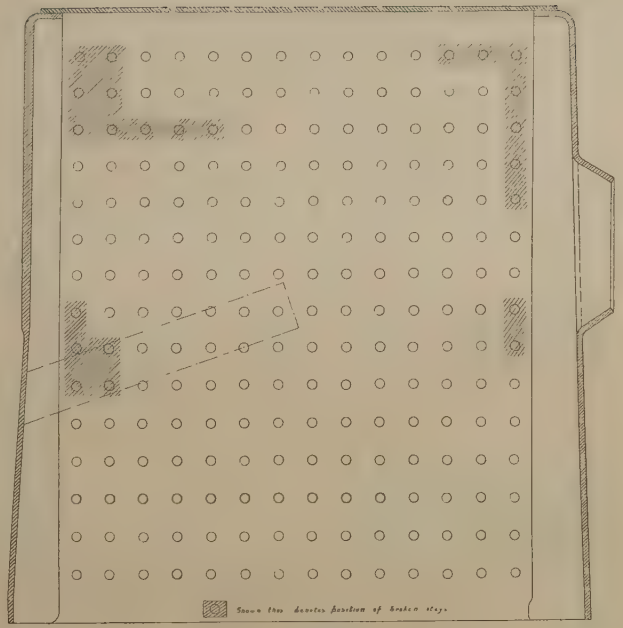
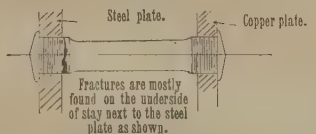
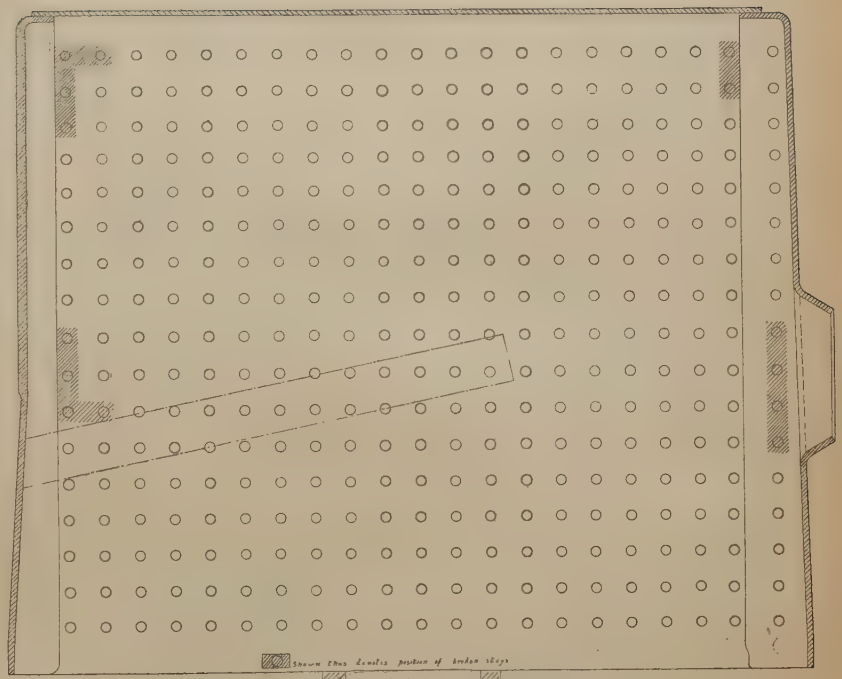
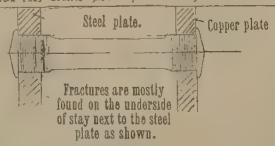




Roof bar fire-box.





Belpaire fire-box.

Fig. 34. — Lancashire & Yorkshire Railway.

the fire-box tend to bulge, thus causing a tearing action on the underside of the stay-head on the fire-box side. The repeated application of this stress, due to the varying pressure in the boiler, seems to be better withstood by the copper than by the bronze stay. Whether or not this is the true explanation, the fact remains that with bronze stays several Administrations state that this trouble of the heads breaking off some two or three threads inside the fire-box plate is of frequent occurrence. It may be mentioned that this trouble is not now so marked on the Midland Railway.

A greater difficulty with stays is the fact that the heads burn away in the fire-box and especially in the line of the passage of the hottest flame as shewn in figure 33. This trouble is not confined to either copper or bronze, and although it is probably more acute with the latter, the greater strength of the material at the steam temperatures in the boiler allows a smaller stay to be used in the first instance, and so a larger number of replacements can take place before the holes in the box side become so large as to necessitate their being bushed or the side renewed. When renewing stays on the Midland Railway, it is not customary to employ bronze when the size of stay required is so large that copper will give sufficient strength.

Position of fracture of stays. — Nearly all railways have trouble with stays fracturing in consequence of their inability to resist the stresses set up in them, these being chiefly due to the difference in expansion of the inner and outer plates, and the tendency of these plates to deform under pressure. As would be expected, the greatest number of fractures occur, as will be seen from table 6, in the top front corner of wrapper-plates, where the movement is greatest. They are found in the back corners and along the top rows of stays, and in some cases in the side plates near the brick-arch and on the fire-line. (For position in Lancashire & Yorkshire Railway fire-boxes see fig. 34.)

The position of the fracture in the stay itself is usually near the steel wrapper-plate on the underside, but occasionally such fractures occur near the copper plate, when they are chiefly to be found on the upper side of the stay (fig. 35). Many of the bronze stays used are, however, rendered somewhat flexible by having four narrow saw-cuts put in them as shewn in figure 36. After the open saw-cuts are

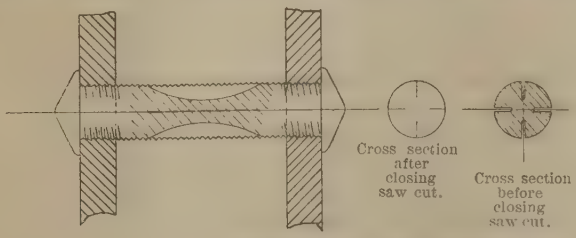


Fig. 36. — Stone's bronze flexible stay with saw cut closed.

put in, and before screwing, the stay is rolled again so as to close in the gap made by the saw.

No stays of flexible type, such as the spherical-headed stay used in the United States of America, are employed by any of the Administrations.

Methods of detection of broken stays. — The old method of detection of broken stays by tapping is still very generally adhered to, but the Natal Government Railways and New South Wales Government Railways drill tell-tale holes into the stays from both ends.

17. — *Lining the fire-box.*

Two of the Administrations are using fire-clay slabs, *viz.*, the Great Central and the Midland Railways. The Great Central Railway states : — " We use fire-clay slabs " to cover the fire-box under the brick arch with good results." On the Midland Railway, their use is still in the experimental stage, but they have proved effective while they have been in use in preventing burning of the stay heads and fire-box plates. Up to the present, they have only been tried under the brick arch on the side plates. The slabs are about 2 feet long × 14 inches wide × 2 inches thick, and their life, as is to be expected from the position in which they are placed, is only short, generally about two months.

SUMMARY OF REPORT.

A.

Probably the greatest change in boiler construction which has taken place in recent years on the Administrations reported upon in the largely increased use of Belpaire fire-boxes, the majority of newly designed engines having been with this type. One great advantage derived from this change is that the disuse of roof-bars leaves the space over the top of the fire-box clearer and more easily washed out, and some of the Administrations who have not adopted the Belpaire box have in their later boilers fitted radial stays with the same object in view. There seems to be less trouble with a copper tube-plate when fitted in a Belpaire than in a round-topped box, but this point is perhaps open to question.

A few of the Administrations employ wide, comparatively short, fire-boxes which are placed over the frames, and the Great Northern Railway of England are getting particularly good results with this type (fig. 37). It readily allows a large grate area and facilitates the renewal of any defective stays, but with passenger engines at all events, entails a smalluncoupled trailing wheel.

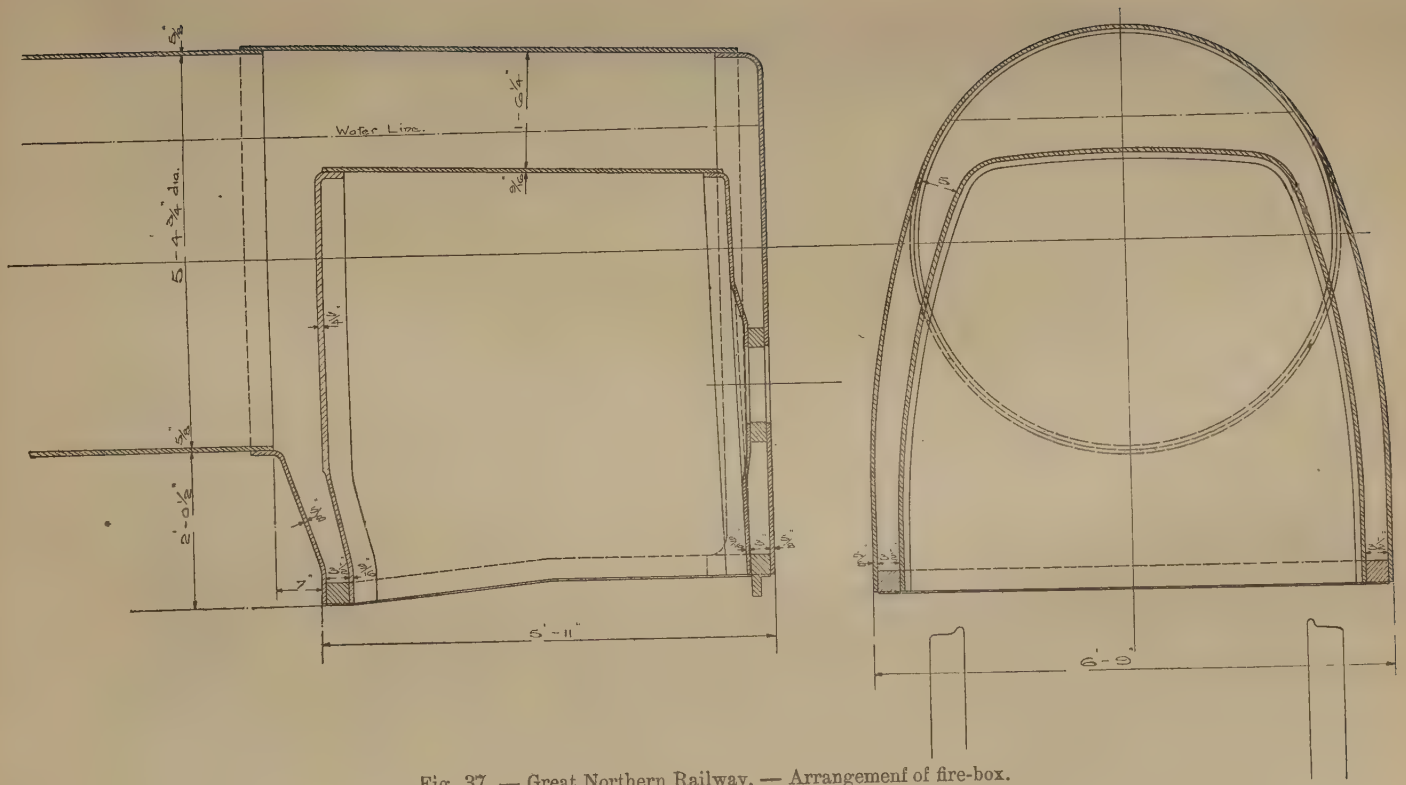


Fig. 37. — Great Northern Railway. — Arrangemenf of fire-box.

248 tubes 2 1/4 inches	2,359 square feet.
Fire-box	141 — —
Total.	2,500 square feet.

Grate area.	30·9 square feet.
Water line area	92·11 — —
Flue area.	5·4 — —
Steam space	66·03 cubic feet.
Working pressure	175 lbs. per square inch.

The weight of the engine, as a whole, has an important bearing upon the design of the boiler, for in order to keep the load per wheel down it has frequently been found necessary to slope the door-plate forward, so as to prevent the load per unit of area on the trailing journals becoming too great, and this in spite of the fact that these bearings are sometimes as much as 10 inches in length and 8 3/4 inches in diameter.

In spite of its high and at times excessive price, copper is still very generally used for fire-boxes on the railways reported upon, and no consistently good results seem to have been obtained with any other material, although one or two Administrations use steel for goods or secondary engines which are not heavily worked. It is interesting to note that although two Administrations have tried cylindrical steel fire-boxes, they have not extended their use. This seems largely due to the difficulty of raising steam in them, owing to the poor circulation due to a considerable body of the water in the boiler being below the source of heat and, therefore, not affected by the convention currents set up.

One of the reasons for the abandonment of steel fire-boxes has been the trouble from corrosion, and to endeavour to meet this, nickel steel has been experimented with, but up to the present has not been found satisfactory.

The advantages of employing high pressure steam are becoming more and more realised, and a number of Administrations use 200 lbs. per square inch, whilst with two it rises to 220 and 225 lbs. In one of the latter, they employ it in compound engines, whilst the other, on which the engines are simple expansion, use the highest pressure met with, *viz.*, 225 lbs. These higher pressures, as might be anticipated, tend to accentuate boiler troubles, and render more imperative the employment of good water and the selection of tubes and longitudinal stays which will not cause excessive distortion of the tube-plate. Some Administrations have found that the troubles associated with higher pressures have not been compensated by the advantages gained, and have returned to a lower maximum.

The question of weldless barrel-plates is of considerable importance, and a large firm of of steel makers in Sheffield have put down extensive plant for the manufacture of these plates, which are being tried by one Administration, at least in England.

On the whole, it may be said that the proportion of steel and iron tubes to copper and brass in growing, and several of the British Administrations have wholly dispensed with the latter expensive metals. In India it may be noted that brass is very extensively used, and pitting just inside the ferrule, due to mechanical action from the coal, does not seem to give the trouble it does on some Lines. As might be expected, steel and iron are much more liable to corrosion than the other metals, especially near the fire-box, and nearly all who use these materials arrange for the renewal of this end of the tube when the corrosion has rendered it unfit for further use. Copper ends and sleeves are occasionnally employed to prevent this defect.

Considerable attention is now paid to the expansion of the tube into the tube-

plate, this being generally carried out by mechanical means. Attention has also been given to the order of expanding, various procedures being adopted to prevent, as far as possible, the distortion of the tube-plate caused by the work put on it during expansion.

Opinions are still divided as to the relative merits of the arrangement of tubes in vertical or horizontal rows, but the former seems to be gaining ground, as it keeps the boiler cleaner, allows steam to rise more readily when working, and scale to fall more freely during washing-out.

Attention is being given in many quarters to the better regulation of the admission of air to the fire, and this should lead to improvement in the maintenance of the fire-box tube-plates; no full particulars are, however, yet available. The question of a forced draught on the " plenum " principle is also being considered, but nothing practical has yet been evolved, and although such a system would effect a great improvement, the quantity of air to be admitted with an express engine is very great, rising in some cases to at least 8,000 cubic feet per minute.

The increase of pressure and harder work to which modern boilers are subjected, has led to more attention being paid to the arrangement and spacing of tubes and stays, especially with a view of giving greater flexibility at the corners where cracking usually takes place.

Although " extended " smoke-boxes are only used by a few of the Administrations, yet there is an increasing tendency to enlarge these boxes with a view to equalising the " draw " through the tubes and preventing to a certain extent the ejection of sparks.

B.

Little has been done with regard to water-tube boilers, and the use of water-tubes in the fire-box of the Drummond type has not met with general favour; but, in addition to the cases mentioned in the Report, we understand that the Japanese State Railways are adopting these water-tubes to a certain extent.

At the time of writing this report, there are only two Administrations in the countries reported on which are using superheaters to any large extent. There are however, a number of others who are experimenting with this type of engine, and it is probable that their use in the countries dealt with will shortly be considerably extended.

C.

The replies received shew that the practice of the different Administrations in regard to water-softening varies greatly, some having adopted it extensively and others practically neglecting it. The softeners in use include the following : Archbutt-Deeley, Desrumaux, Kennicott, Pulsometer, Reisert, Porter-Clark and Wollaston. In one case, Mirrlees-Watson Yaryan Distillers are used. The chemicals used in softening are invariably lime and soda.

When the proportion of soluble salts in the concentrated boiler-water reaches from about 214 to 500 parts per 100,000 (150 to 350 grains per gallon), the amount varying with the type of boiler, rate of steaming, and nature of the salts, foaming of the water is sufficient to cause serious priming, and for this reason it is found necessary to limit the amount of soda used in softening. To overcome this difficulty, some railways have tried barium compounds in place of soda or soda-ash in softening, but the cost has always been found to be prohibitive; in fact, with some waters it may be as cheap or cheaper to distil the water and thereby remove all impurities as to soften with barium salts.

The experience of those railways which have adopted water-softening shews that great saving is effected thereby in the cost of re-tubing boilers, replacing broken stays, and removing scale, whilst leakage is practically stopped. Two Administrations record a large saving by being able to soften and use water which can be obtained cheaply, instead of purchasing expensive water of better quality.

Since the date of the last report (1900), the use of water-softening plants has considerably extended amongst the railways reported on, and we do not doubt that it will continue to extend as the saving which is capable of being thus effected becomes better realised. One reason why progress in the past has been slow, is the fact that water-softeners were regarded as machines which required no scientific control and could be efficiently run by the labourer in charge. Most railways now employ chemists, and it is realised that the water-softeners should be placed under the supervision of the chemical as well as of the engineering staff. Those Railwayr which have been working on these lines, find that the results obtained well repay the cost entailed by water-softening.

To obtain the best results, water-softening should be used in conjunction with a system of changing the water in the boilers before it has become too concentrated in regard to sodium salts, or saturated as regards that part of the calcium sulphate which cannot be economically removed without unduly charging the water with sodium salts. To enable the water to be changed with the necessary frequency, and without engines spending too much time in the shed, the boilers must be filled up with hot water. When the amount of sodium salts or calcium sulphate in the original water is excessive, undue concentration can only be prevented by the use of blow-off or scum-cocks, of some description. The practice adopted must be based upon and controlled by a systematic chemical analysis of the principal waters used by the locomotives in each district.

Disincrustants are used in the boilers by a few railways, those most commonly employed being preparations containing tannin or soda alone, or a mixture of the two. The experience of some Administrations has been unfavourable, others have given up the use disincrustants in favour of water-softening.

Several railways have contributed analyses of specially corrosive waters, the results of which are given in the body of the report.

For the prevention of corrosion, some railways obtain good results by coating

the boiler plates with Portland cement; but in one case it wat found that in the boilers in which this was used it washed off and was a failure. A coating of graphite and boiled linseed oil has been tried, but was found to percolate through the seams and joints and cause leakage. On one line the boilers are painted inside with tar and graphite. Zinc plates and plugs have been tried by several railways, with unsatisfactory results. Some Administrations have found the addition of a definite excess of slaked lime to the water distinctly advantageous in preventing corrosion, especially in the case of natural soft waters.

The majority of the railways still use cold water for washing-out boilers, but the use of hot water is extending.

On many lines the use of blew-off cocks or scum-cocks to prevent priming is necessitated by the bad quality of the water which has to be used.

There seem to be no special features in the replies to questions on cracks, pitting, grooving and general surface corrosion, as all the Administrations suffer more or less from these defects in much the same manner and in the same position in the boilers. Although various steps have been taken to prevent these troubles, none seem to be universally satisfactory. Efforts are being made to increase the water-spaces around the sides of the fire-box to prevent breakage of stays and corrosion of fire-box plates; to give larger radii at corners and prevent the tubes from coming into close proximity to the edge of the tube-plate to lessen the chance of cracking, etc., and these doubtless help to minimise the troubles; whilst water-softening and mechanical cleaners also help in this direction.

Practically two, and only two, types of material are employed for boiler stays, *viz.*, copper, and a bronze (Stone's), containing copper with nickel, manganese and iron. (For analysis see table 6, reply from Midland Railway.) The latter material is stronger at boiler temperatures than copper, but the head of the bronze stay tends to burn off more readily than copper, and some Administrations state that the heads are liable to break off in the fire-box plate.

There does not seem to be a great deal of trouble with stays fracturing, except at the top front corner of the fire-box, and even here the trouble is not marked enough to cause the special flexible stays, as used in America, to be adopted.

APPENDIX I.

Detailed list of questions relating to question VI.

QUESTION VI-A.

Boilers with smoke tubes ; precautions in constructing and maintaining tubes and tubes-plates.

1. What type of boiler do you use? Belpaire or round-topped? Please forward drawings of your latest standard types.

2. If you use round-topped boilers, do you use roof-bar or radial stays on the fire-box crown sheets? Kindly state what special advantages you find from each type.

3. Have you any locomotives fitted with cylindrical fire-boxes? If you use this type, please submit drawings and describe the advantages or disadvantages derived from the use of this design.

4. Are any of your boilers fitted with combustion chambers? If so, please supply drawings and state what results have been obtained with this method of construction.

5. Have you constructed any boilers with fire-boxes of any other material than copper? If so, what have been the results compared with copper fire-boxes of the same design?

6 What shape and size of firehole do you find the most suitable? Do you employ any special door or other special means of air-admission? Do you use a ring joint or dished joint between the inner fire-box plate and back plate? If the former, how is it fastened?

7. What is the proportion between the total grate area, air-space in the firegrate, and total tube area? Are any of your boilers fitted with rocking or drop grates?

8. In very long boilers, do you employ any form of intermediate support for the barrel of the boiler?

9. Which type of front tube-plate do you fit your boilers with, viz., drum-head, or plate with extension fitted to the cylinder casing?

10. What material are your tubes constructed of? Give reasons for the adoption of the metal or alloy you employ.

11. What are the dimensions of tubes used in your standard type of boiler, including thickness at each end?

12. What is the method employed in fixing tubes in your boilers? Kindly give a description, with sketches, of any special machines or device employed for this purpose. Are the tubes expanded in any particular order?

13. Have you had any experience with Serve tubes? If so, please supply particulars.

14. Are you troubled with

a) Pitting of steel or iron tubes?

b) Excessive wear or fracture of copper or brass tubes just inside the copper tube-plate?

What steps do you take to counteract these defects? Have you tried galvanized steel or iron tubes, and, if so, with what results?

15. Do you employ ferrules in tubes? If so, with what object in view, *e. g.* :

a) Keeping the tube tight?

b) Protecting the end of the tube from the action of the fire?

What taper and thickness of ferrule do you use? Do you bead the ends of your tubes and, if so, with what results? If this has been tried and given up, what cause led to its being discontinued?

16. How are your tubes arranged in the tube-plate, *i. e.*, in vertical or horizontal rows? State the reason for your practice. What space is allowed between the tubes?

17. Do you employ pressures above 180 lbs. per square inch and, if so, have any special means had to be taken to cope with these pressures, especially in the keeping of the tubes tight and in maintaining the fire-box tube-plate in good condition?

18. Has it been found that any special spacing of the tubes or stays has led to a decrease in the trouble experienced from cracked corners of the tube-plate?

Have you tried cold hammering of the copper tube-plate in order to harden it and, if so, with what results?

19. Do you use an extended smoke box? If so, what advantages are derived from it?

20. In your latest standard types of boilers, do you fit a steam-dome and, if not, what device is in use to obtain dry steam?

21. What material is used for lagging your boilers? Are the boilers lagged inside the cabs? If you have made any tests to ascertain the relative efficiency of different lagging materials, kindly give particulars and results.

22. Do you employ any system of thermal storage and, if so, what advantage do you derive from it?

Question VI-*B*.

Boilers with water-tubes. — Steam superheaters and valve gear for superheated steam. Feed water heaters.

Boilers with water-tubes.

1. Do you use water-tube boilers on your system? What advantages have been gained by substituting them for fire-tube boilers? How do the water-tube boilers work in comparison with fire-tube boilers? Is it possible with water-tube boilers to increase the heating surface more than with fire-tube boilers, by lengthening the boiler barrel?

2. Do you use water-tubes in the fire-boxes of your locomotives? Do the results obtained justify the increased expenditure incurred by putting them in and maintaining them?

3. Kindly furnish us with drawings of the methods you employ in both the above cases.

4. Have you made any analyses of the smokebox gases to ascertain what effect, if any, the water-tubes have in preventing complete combustion? If so, please state the results.

Steam superheaters and valve gear for superheated steam.

1. Do you employ superheated steam? If so, kindly give a description, with drawings, of any system you use.

2. Do you use a special valve gear on your superheated locomotives? If so, give description and drawings.

3. What means do you employ of ensuring tightness with freedom of movement of the pistons and valves? Please give detailed drawings. Do you use piston valves with solid rings or with spring rings? What are the reasons in favour of either system.

4. Give a description, with drawings, of the packing employed for the piston and valve rods. If metallic packing is employed, give the composition of the metal or alloy used.

5. Give drawing of the piston rod, including the cross head and tail rod, shewing the method of fixing the piston on the rod. Of what metal do you make the pistons? Do you grind the piston rods, either when new or when under repair?

6. How long have you used superheaters? How many locomotives so fitted have you in service or under construction?

7. Have you used superheated steam for compound locomotives? If so, do you superheat the high pressure or low pressure steam, or both? Give drawings shewing the means adopted for superheating the high pressure or low pressure steam, or both.

8. Have you made any experiments for determining the effect of superheating? If so, kindly state :

a) The saving in water and coal,
b) The additional power and any other advantages realised.

What is the maximum superheat obtained when the locomotive is working at its greatest power. Please, also, give with these results, a comparative table shewing the principal dimensions of locomotives with and without superheaters including :

a) Grate area,
b) Heating surface and superheating surface,
c) Weight of locomotive light,
d) Working pressure of the boiler,
e) Size of cylinders, etc.

Further, if you have experimented with simple-expansion or superheated locomotives in comparison with compounds, please give the results and principal dimensions of the engines

between which the comparison was made. Have you been able to reduce the weight of the two cylinder simple locomotive, using superheated steam, to that of the compound locomotive of the same power using saturated steam?

9. Where do you measure the amount of superheat attained, and with what apparatus? What fall of pressure have you found between the boiler and the valve chest? Is the pressure of the steam when admitted to the cylinders higher than when saturated steam is used for the same boiler pressure? Have you found any definite relation between the degree of superheat, additional power, and economy obtained? Have you established any relation between the total heating surface and the superheating surface? Has the employment of the superheater enabled you to reduce the working pressure of the boiler? What is the increase in the dimensions of the cylinders which you have adopted for the superheated locomotives?

10. What is the saving of fuel and increase of power obtained by the use of superheated steam in comparison with saturated steam on similar locomotives taken on the same mileage?

11. What increase has taken place each year in the time the locomotive is out of service for repair of the superheater, packings, etc? What is the annual cost of the maintenance and repair of this apparatus? Has any part of the superheater caused you any particular difficulty? Is the superheater sufficiently accessible in case of repair? Have you observed any blocking up or wearing out of the tubes of the superheater? With Schmidt's superheater, placed in the fire-tubes, have you found any distortion of the fire-box tube-plate between the bottom row of large tubes and the top row of small tubes?

12. What is the extra cost of oiling superheated locomotives? What class of oil do you use for the cylinders? State whether a pure mineral oil, or a mixture of mineral oil and fixed oil, and, if the latter, please give the composition. Please also give the viscosity, specific gravity, and any other characteristics which you have determined of the mineral oil. Do you use mechanichal or sight-feed lubricators, and what type?

13. Have you given any special instructions to your staff concerning the management or driving of these locomotives, and as to the attention required by the pistons and slide valves? Attach a copy of these instructions.

Feed water heaters.

1. Do you use feed-water heaters? If so, please furnish drawings and descriptions.

2. Do you employ injectors or pumps? Please describe the means adopted for preventing the water from attaining such a temperature as would impede the action of the pump or injector.

Question VI-*C*.

Damage to boilers, pitting, grooving, and corrosion. Means employed to prevent this damage. Purification of water and disincrustants.

1. What process, or processes, do you use for softening water? Give particulars of the chemical treatment, stating what chemicals are used; and, without describing well-known methods, give details of any special methods or apparatus you employ, or any special details

connected with the working of the ordinary methods of treatment which you have found advantageous. What precautions are observed to ensure the treatment being properly carried out?

2. State whether you are satisfied with the results obtained and, if possible, give figures shewing the saving effected in :

1° Fuel;
2° Cost of cleaning and retubing boilers;
3° Cost of repairs to and life of boilers;
4° Cost of water (*i. e.* by being able to use water which can be obtained cheaply, instead of having to purchase expensive water of better quality).

3. How do you deal with waters of which the hardness is mainly or largely due to calcium and magnesium sulphates, chlorides or nitrates? Do you soften such waters, and if so, what precautions do you take to prevent priming of the boilers caused by sodium salts introduced in softening?

4. Have you used barium hydroxide, barium carbonate, or barium aluminate in softening water containing sulphates. If so, please give particulars, results and cost of treatment, and state whether you find it pays.

5. Have you made any attempt to ascertain the quantity of sodium salts present in the water of locomotive boilers when priming commences? If so, please give particulars and results of these experiments.

6. Do you use, or have you used, disincrustants placed directly in the boilers, instead of treating the water before use? If so, state the nature of the materials used, and the results obtained.

7. In connection with water softening or the use of disincrustants, have you been troubled with excessive leakage of boiler tubes or stays? If so, kindly give particulars, stating what you conceive to be the cause of the leakage and whether any and, if so, what means you have found effectual in preventing or lessening this leakage.

8. On what portions of the interior of the boiler do the following defects occur :

1° Cracks;
2° Pitting;
3° Grooving;
4° General surface corrosion.

9. When the boilers undergo heavy repairs, are any notes made on the repair sheets as to the defects mentioned in question **8**? Are sketches made on the sheets illustrating the actual nature, position and dimensions of these defects? If so, kindly supply some of these sheets chosen from amongst those giving the most characteristic defects.

10. What are the methods employed in the construction of boilers to prevent any of the defects referred to in questions **8** and **9**? Have modifications been carried out in the design of the boilers with this end in view? What is the breadth of the water-spaces in the fire-box? Where is the feed-water delivered, and in what manner?

11. Are the boilers washed out with cold or hot water? What are the mean mileages between two washings-out? In fixing these mileages, is account taken of the quality of the water? What is the time allowed for cooling down before the boiler is washed out with cold

water? What pressure of water is used for washing-out? If any system of washing out with hot water is employed, kindly describe this fully.

12. Is blowing off a portion of the water under pressure resorted to in order to prevent the formation of deposit and to check priming? If this practice is carried out, at what time and after what intervals is it done? What means are adopted to remove the water? Shew by sketches the position of the blow-off cock and its design.

13. If you have any waters which are specially corrosive to boilers, but which by analysis are not found to contain free mineral acid, please give analyses stated in parts per 100,000 shewing (if possible) the amounts of

Lime (Ca O).
Magnesia (Mg O).
Soda (Na_2 O).
Alkalinity (as Ca C O_3).
Sulphuric anhydride (S O_3).
Nitric anhydride (N_2 O_5).
Chlorine (Cl).
Carbon Dioxide (C O_2), free.
Total Solid Matter at 130° C.

14. Have you tried to prevent corrosion by coating the insides of boilers with Portland cement or any kind of paint, or by treating the water with a definite excess of lime or other chemical to neutralize carbonic or other acid, or by introducing chemicals or other substances into the boilers? If so, please give full particulars and results.

15. Do you use zinc plates in your boilers? If so, explain, with sketches, the method of application and the results as regards

1° Prevention of incrustation;
2° Prevention of pitting and corrosion.

16. What metal or alloy is used or has been tried for fire-box stays; if any metal other than copper or iron, give composition. What advantages have been found to result from the use of these other metals or alloys? Is any trouble experienced with stays breaking; if so, please state where these fractures occur and indicate:

1° The position in the stay itself;
3° The position of the stays in the box.

Are any special means adopted to detect fractures? Is any type of flexible stay used? Are you troubled with stay heads burning away and dropping off in the fire-box? If so, what means have been adopted or tried to prevent this, and with what result?

17. Have you tried lining the fire-box or any part of it with firebricks or fireclay slabs to protect the stays from the action of the fire and to promote better circulation of the water in the fire-box; if so, give results, and state the nature and composition of fire-resisting material used.

APPENDIX II.

The Brotan patent locomotive boiler with water-tube fire-box.

This is a locomotive boiler with the usual fire-tubes running through the barrel, but the fire-box, instead of having plain sides surrounded by a water-space, is formed by a series of tubes arranged as shewn in figure 38, which rise up the sides of the " box ", and then arch over to meet a steam collector which runs for the whole length of the fire-box and boiler. In the earlier form, a steam dome was fixed on this collector at the smoke-box end, but in a more recent design the collector terminates at the front end of the fire-box where it enters the boiler barrel. In addition to the collector it is necessary that the full complement of fire-tubes shall be fitted, as these must all enter the tube-plate. To make this possible, the barrel is coned as shewn. As will be seen, the fire-box water-tubes surround the sides and back of the box, but on the front side they curve round the fire-box tube-plate and thus make the fire-tubes readily accessible. At their upper ends, the water-tubes are expanded into a one-inch plate, forming the bottom plate of the box at the back and sides. This pipe carries the fire-bars and forms a connection for the water passing from the barrel through the quadrant-shaped connecting pipes shewn, to the water-tubes. On its lower side are 2-inch holes placed opposite to the water-tubes, thus making it possible to expand these into position with a tube-expander.

The water-tubes are held together by several bands which radiate from the frame of the fire-door, bend round and pass thence to the shell-plates to which they are secured. The fire-door frame is fastened by means of a turn-buckle placed between it and the cast steel pipe, previously mentioned as running round the fire-box bottom. The whole of the fire-box is covered by an outside casing, and the space between the casing-plate and the water-tubes is filled up with a plastic composition, made of asbestos scrap mixed with fossil meal.

The general level for the water is about the centre of the collector drum, the highest and lowest levels varying about 4 inches on either side of this mean level.

The advantages claimed by the inventor for the Brotan boiler are as follows :

1° There are not any rivetted parts exposed to the fire, nor flat fire-box walls that would require strengthening by stay and anchor bolts. Therefore, all the defects of the ordinary locomotive fire-box are avoided.

2° The system of the upright water-tubes with the water supply at the bottom creates an active circulation of the water, facilitates the rapid rising of vesicles, and transmits the heat in a very effective way through the walls, which are only $^3/_{16}$ inch thick. Quick steaming is thus secured.

3° The active circulation of water renders formation of scale, especially in the water-tubes, impossible; besides this, the tubes may be easily and thoroughly cleaned, both from above and below, with wire brushes, which enhances the safety in working.

4° Although its diameter is smaller than that of the ordinary boiler, a greater number of fire-tubes can be fitted in. Furthermore, the direct heating surface, which is far more effective, is 50 per cent greater than in the ordinary boiler. The Brotan boiler has, therefore, a greater heating

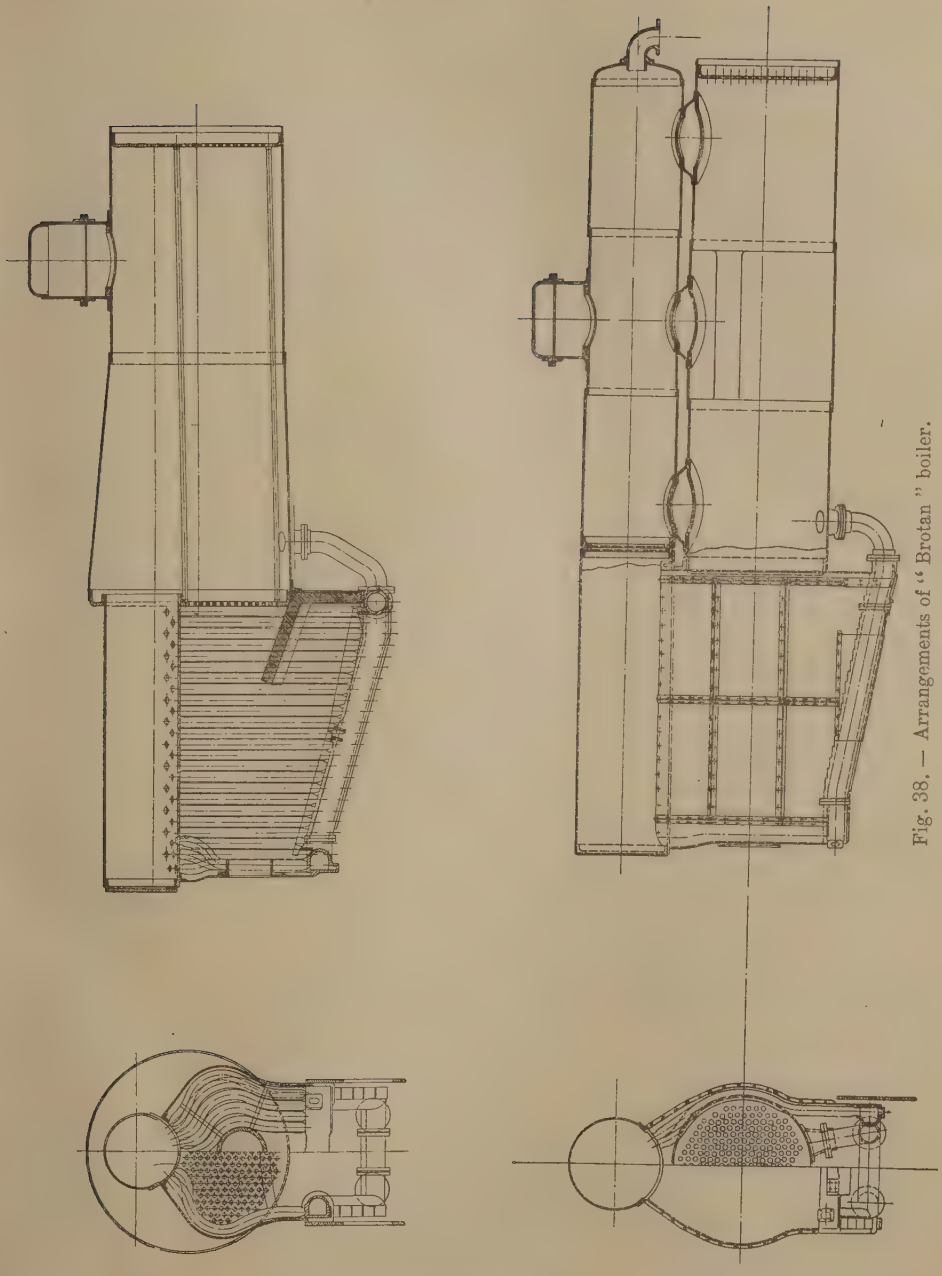


Fig. 38. — Arrangements of " Brotan " boiler.

*

surface without increasing the weight or the fire-grate area, secures better combustion of the coal and increases the steaming capacity.

5° The difficulties which arise in the ordinary fire-box, when steam pressure in increased, are removed, and an explosion of the locomotive boiler... is almost entirely out of the question.

6° The cost of manufacture of the Brotan boiler is about 20 per cent cheaper than that of the ordinary boiler; the maintenance is far less, and if a defect should occur in any of the tubes, notwithstanding the high pressure of 750 to 900 lb. to which they have been tested, the same can be replaced in a few hours, being cut out with a chisel at the top and bottom from the inside of the fire-box. The new tube is also put in place from the inside of the fire-box. The necessity of replacing the whole of the water-tubes has not yet been experienced in the five years these boilers have been working. If the bent tubes are kept in stock, the old ones may be removed and the new ones fitted within fourteen days.

APPENDIX III.

Instructions for handling engines fitted with Schmidt superheaters on the Lancashire and Yorkshire Railway.

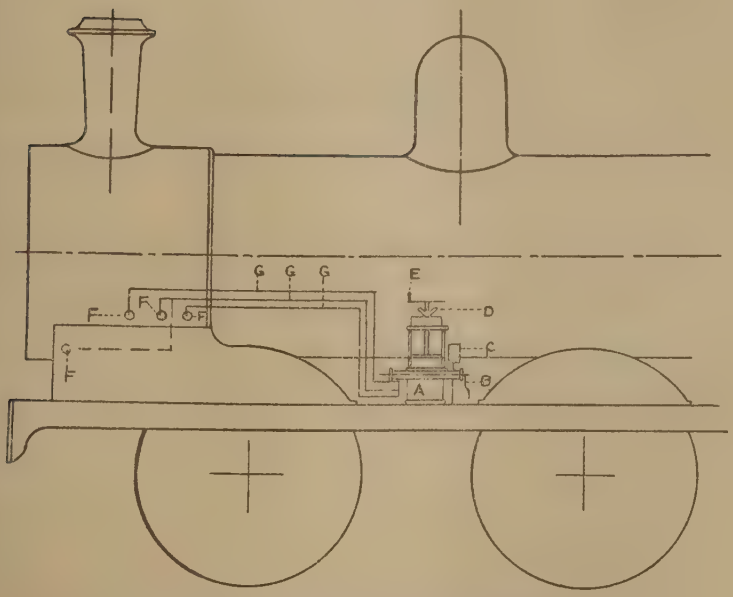


Fig. 39. — Lancashire & Yorkshire Railway.
Instructions for handling engines fitted with "Schmidt" superheaters.

Diagram of mechanical lubricator:

A	= Lubricator.	E	= Lubricator.
B	= Filler handle.	F	= Testcocks and back pressure valves.
C	= Oil chamber.		
D	= Flynut.	G	= Oil-pipes.

1. — *Before the start* the lubricator test cocks F which are fitted on the smoke-box and front sand-boxes on both sides, must be opened, to see that the pipes G are full of oil. Failure at any point must be rectified by loosening the flynut D on the lubricator, and turning the handle E to the left until oil appears. Then shut the test cocks, turn the lubricator handle another $^1/_4$ turn, and lock the flynut. The engine driver must particularly see that this rule is carried out.

2. — In case air gets into the oil-system, the oil should be drained out, and the pump refilled again.

3. — When charging the lubricator, the oil chamber C must be filled first, the handle B at the base of the lubricator raised, the flynut D at the top loosened, & the handle E turned to the right until the oil is all sucked out of the oil chamber C. The fly-nut D must then be tightened and the handle B at the base pushed down to its lowest position.

4. — The cylinders should be warmed up thoroughly, and cylinder cocks opened until the temperature in the steam-chest reaches about 400° Fahr., when the cocks may be closed.

5. — Special attention should be paid to the springs of the relief valves, and the drain cocks of the cylinders should be free.

6. — *Running.* — The temperature of the steam in the steam-chest should average 600° Fahr., and care must be taken not to exceed 660° Fahr. Regulation of this may be made with the smoke-tube dampe-handle or wheel in the cab.

7. — The damper-handle for the superheater smoke-tubes should be moved to the shut position when the regulator is closed, and vice-versa. This does not apply if the engine is fitted with automatic gear for opening the damper doors.

8. — Immediately the regulator is closed, the bye-pass valves must be opened whilst the engine runs without steam or comes to rest, when they may be closed ready for next start.

9. — When starting, the regulator, should not be opened too quickly.

10. — To avoid slipping when starting, the engine must be notched up immediately the engine starts, governing being effected by the reversing gear.

11. — The engine should not be notched beyond 1 $^1/_2$ notch, further necessary adjustment being made with the regulator.

12. — The engine driver can always tell whether the lubricator works all right, by watching the turning of the handle E.

13. — In case the temperature of the superheat goes back suddenly, priming is taking place, and the boiler requires washing-out.

14. — *After the trip.* — Every time the engine comes to the shed, the superheater smoke-tubes should be cleaned out with the flue-cleaner from the fire-box end, and if necessary, from the smoke-box end.

15. — The lubricator should be filled up with special oil for superheaters immediately after each trip and the handle E taken off, to prevent misuse.

APPENDIX IV.

[1139]
Inspector's No. ...

C.M.E.
56

Western Australian Government Railways.

Locomotive. Boiler No. *10.* Class " *A* ". Now in locomotive : *10.*

Examined at *Fremantle workshops*, on *19th February, 1904.*

Boiler made by :	Maker's number :	Date on maker's plate :	Date when boiler commenced to work :
Beyer Peacock & Co., Limited Manchester.	*2651.*	*1885.*	*6th July, 1885.*

1. Original working pressure : *130.* Lbs. per square inch :	2. Date of last test : *2nd September, 1901.*
3. Date of last examination : *7th January, 1904.*	4. Date when boiler was last clothed and tubes put in : *Clothed 2nd September, 1901.*
5. Working pressure at inspection : *nil.* Lbs. per square inch :	6. Last approved pressure : *120* lbs. per square inch, and date of same { *14th July, 1903.* / *Nil on 21st January, 1904.*

Condition of :		
	7. Fire-box, internal : *Good.*	14. Water spaces : *Good.*
	8. Fire-box, external : *Good.*	15. Stays (all.) : *Good.*
	9. Fire-box shell internal : *Corroded around stays.*	16. Washout plugs or doors : *Good.*
	10. Fire-box, shell, external : *Good.*	17. Lead plugs : *Good, standard.*
	11. Barrel, internal : *Slightly pitted.*	18. Steam-gauge and maker's name : *Good, Bourdon. No. 8640. 9th December, 1903.*
	12. Barrel, external : *Good.*	19. Safety valves and type : *Good lever and spring balance.*
	13. Tubes : *Good.*	20. Boiler mountings : *Good.*

Least thickness of (state position and area; also give average thickness of plates) :		
	21. Barrel : *5/16 inch where pitted along bottom. 3/8 inch average thickness.*	23. Fire-box : *1/2 inch general thickness.*
	22. Fire-box shell : *3/8 inch general thickness.*	24. Tubes : Age *various.* Material : *Brass, whole.* No. pieced : — Date pieced : — Min. weight at piecing—Min. : *17 lbs.*

Locomotive. Boiler No. *10.* Class "*A*". Now in locomotive : *10.* (*Continued.*)

25. Describe fully any patches or additions that may be attached to any portion of the boiler. Give sketch (to scale) of any new ones put on, with dimensions, material, maker's name and brand; show how attached, and date of same :

New copper fire-box complete.	*April, 1897.*
New external fire-box shell, Lowmoor iron	
New smoke-box tube-plate	
A patch 2 ft. 9 in. long by 9 inches put on bottom of front ring of barrel. Material $^{7}/_{16}$ *inch Farnley.*	*19th February, 1904.*

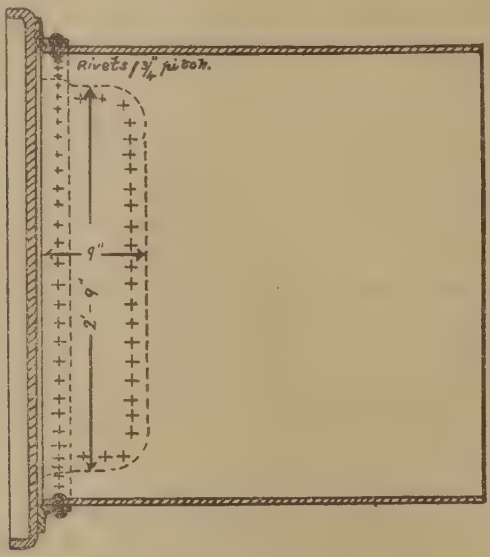


Fig. 40. — Western Australian Government Railways. — $^{7}/_{16}$ inches Farnley iron patch secured with $^{3}/_{4}$ rivets.

26. Describe fully any defect in boiler or mountings : *Smoke-box tube plate is corroded over inner surface of tube holes* $^{3}/_{16}$ *inch also grooved* $^{3}/_{16}$ *inch around bottom.*
Barrel is pitted $^{1}/_{8}$ *inch deep in a few places along bottom.*
Fire-box shell is corroded $^{1}/_{16}$ *inch deep around a few stays. Back plate of fire box is cracking in the root of flange both sides : the cracks are 12 inches long, but are still tight; there are 3 surface cracks in between tube holes in fire-box tube plate.*

27. Repairs recommended : *Nil.*

Locomotive. Boiler No. *10.* Class "*A*". Now in locomotive : *10.* (*Continued.*)

28. Repairs effected, and date of completion of each : *All roof girders removed, and crown of fire-box cleaned. A patch 2 ft. 9 in. long by 9 inches wide put on bottom of front ring of barrel (as marked). Boiler retubed with whole tubes. Boiler mountings overhauled, steam gauge and safety valves tested. Boiler tested.*

Completed 19 February, 1904.

29. Working pressure recommended : *120* lbs. per square inch.

30. Boiler stripped and tested with warm water on : * *19 February, 1904 to 180* lbs. per square inch.
Steam. *19* — *1904 to 130* lbs. —

N. B. — If the boiler is not stripped the word "stripped" should be crossed out; also, if it is only examined and not tested the words "not tested" should be written following the *asterisk* *.

Every portion of the boiler is to be thoroughly examined, and nothing is to be neglected in reporting that is in any way deserving attention.

....., boiler inspector.
(*Signed*) *E. A. Evans*, workshop manager.
C. Groves, *F. B. M.*

Date, *22 February, 1904.*

APPENDIX V.

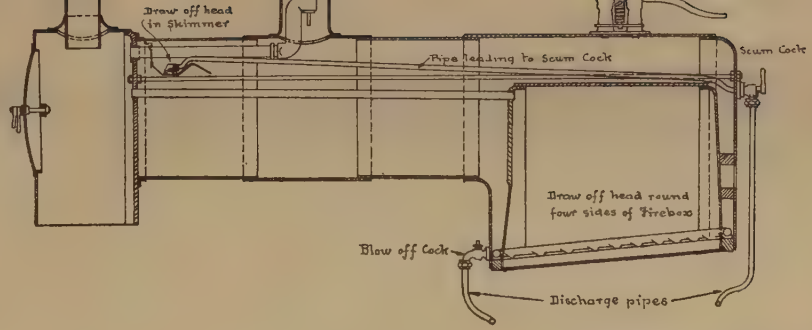
Hulburd (late Hornish) patent mechanical boiler cleaners.

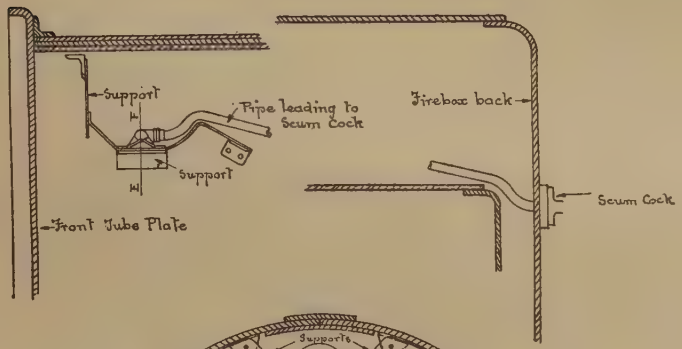
It will be noticed from the replies under "Blowing-off boilers" that the North Eastern, Eastern Bengal State and Central South African Railways are using these cleaners, and a description of them is herewith given.

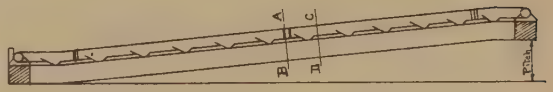
The Hulburd Patent Mechanical Boiler Cleaner, for a drawing shewing the general arrangement of which see figure 41, consists of certain fittings arranged in the boiler barrel and fire-box water spaces, from which by means of scum and blow-off cocks, the collected sediment may be drawn away. A trough is fixed in the boiler barrel transversely to the length of the boiler, just below the level of the water-line and behind the smoke-box tube-plate. A deflector plate is shewn on the right-hand side of the trough (see fig. 41) which ensures the scum being led into the trough bottom. In this trough is arranged a pipe with vertical holes at the end of short projections on its under side. This pipe is connected to another, which pipe runs through the barrel to an ordinary scum-cock placed on the fire-box back-plate in the cab. The trough is said to collect a large percentage of the boiler sediment, which is drawn out from it up the vertical holes and discharged through the scum cock. A somewhat similar arrangement is fixed round the foundation ring as shewn, but in this case there is no need for a special trough, as the upper surface of the ring and the plates on either side of it make this unnecessary. The collecting pipe is in two halves and rests on the ring (see fig. 41*a*), each half being connected to a separate blow-off cock fixed in the front of the throat-plate, and the sediment collecting in the bottom of the water-spaces is said by this contrivance to be satisfactorily removed.

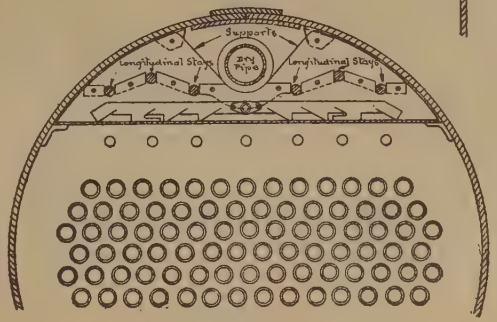
The fitting of these Cleaners does not make it possible to dispense with periodical washing-out, but it is claimed that the time between these can be considerably increased.

If the Cleaners are to prevent accumulations of sediment, the scum-cocks should be used every few hours the boiler is under steam; the blow-off cocks are used after the day's work, before the engine is taken into the shed.









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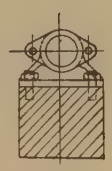

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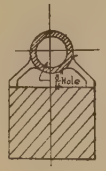

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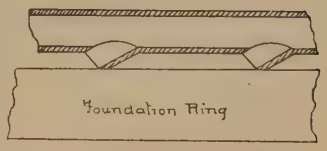


Longitudinal section of draw off head.

Fig. 41. — Hulburd's (Hornish) boiler cleaner.

APPENDIX VI.

Locomotive water supplies in South Africa.

Mr. H. M. Beatty, C. B., chief locomotive superintendent of the Cape Government Railways, has given us the following useful information with reference to the water supplies in the South African Colonies.

"The water used for locomotive purposes in this country varies from very good to very bad; it also varies with the seasons, and up country with the amount of the rain-fall. Generally speaking, the water for the first 150 miles from the coast ports is good all the year round, except in years of drought, when the extremely hard water from the underground springs contaminates what fresh water there is left in the rivers, and makes it very bad for locomotive purposes. These unfortunate conditions disappear as soon as the rain comes. Above the 150 miles limit from the coast, when you get into the high veldt and the barren Karroo the water is, as a rule, very hard, with the exception of the rain-water that we store in dams, and even that in times of drought gets so contamined that it is very bad for locomotive purposes. When the rain comes, all the dams get filled up with fresh waler and the trouble ceases. North of the borders of the Cape Colony in the Bechuanaland Protectorate, the Transvaal and Orange River Colony, which are more or less grass country, the water is as a rule fairly good for locomotive purposes, except in times of drought. The water in Rhodesia, so far has I know the country, is as a rule very good for locomotive purposes We work trains through from Mafeking to Bulawayo, a distance of 500 miles, without changing the locomotive, and frequently turn it back after a few hours stay at Bulawayo, thus making a round trip of 1,0)0 miles, which could not be done except with good water."

[621 .133.3 & 621 .134.3]

REPORT N° 5

(America)

By H. H. VAUGHAN,

ASSISTANT TO THE VICE-PRESIDENT, CANADIAN PACIFIC RAILWAY.

A. — Boilers with smoke tubes; precautions in constructing and maintaining tubes and tube-plates.

Type of boiler. — The type of boiler generally used in the United States and Canada is that with a round top fire-box of what is termed the extended waggon top style in which the diameter of the circular portion of the fire-box and the rear portion of the barrel is larger than that of the front portion of the boiler. Usually the course of the boiler next the fire-box and the front course of the boiler are both cylindrical in form, joined together by a middle taper course. The dome is usually placed on the course next the fire-box.

Representative examples of this type of boiler are illustrated in figure 1, showing a boiler used on the Lake Shore & Michigan Southern Railway, and figure 2, showing a boiler used on the Union Pacific Railroad. They may be regarded as good examples of recent boiler designs in the United States and Canada. A few of the largest administrations, such as the Pennsylvania Lines including allied roads, and the Great Northern, are using the " Belpaire " fire-box, while others, such as the Illinois Central and Canadian Pacific Railways, have used the " Belpaire " more or less extensively, but in each case the latest engines have been equipped with round top boilers.

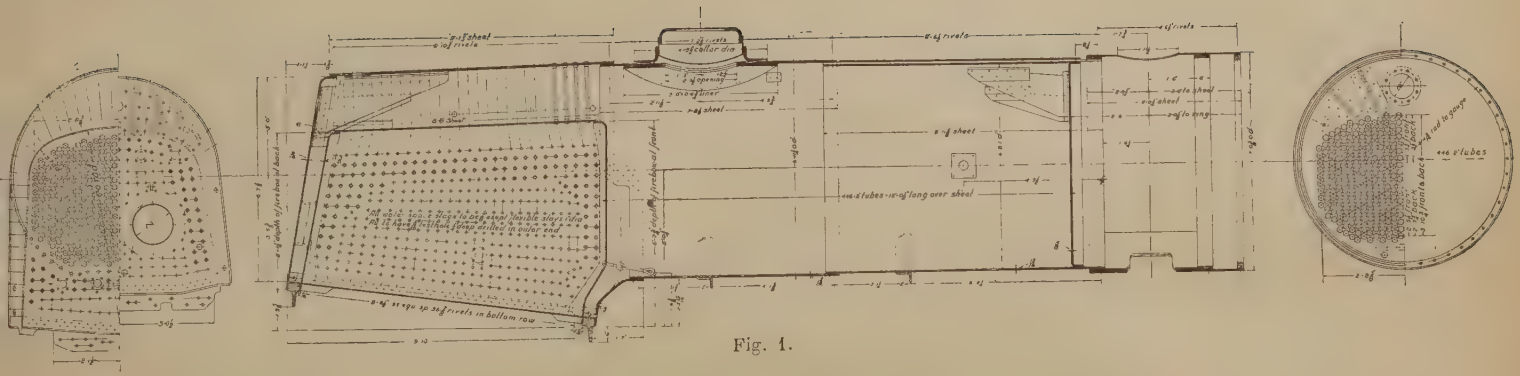


Fig. 1.

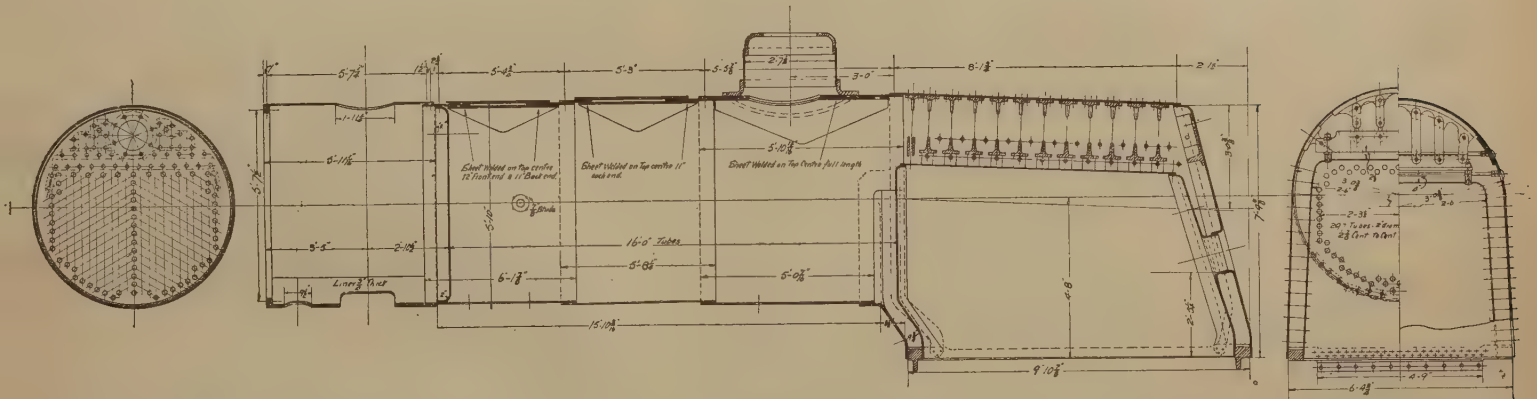


Fig. 2.

Note. – Rigid stay bolts must be 7/8" diameter 12 threads per inch with body slightly reduced below diam. of bolt at bottom of thread with large fillets.

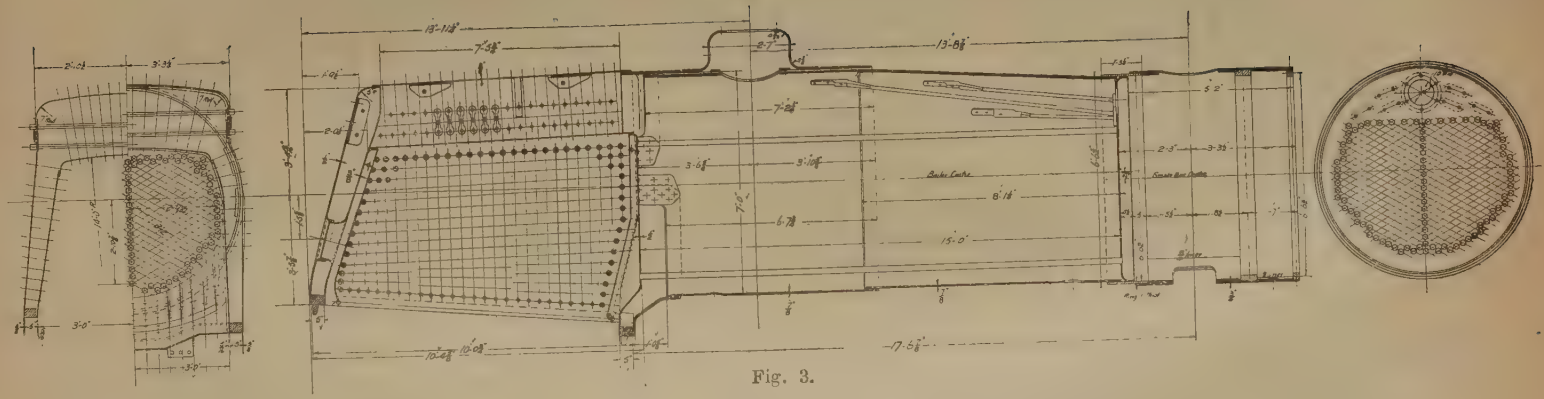


Fig. 3.

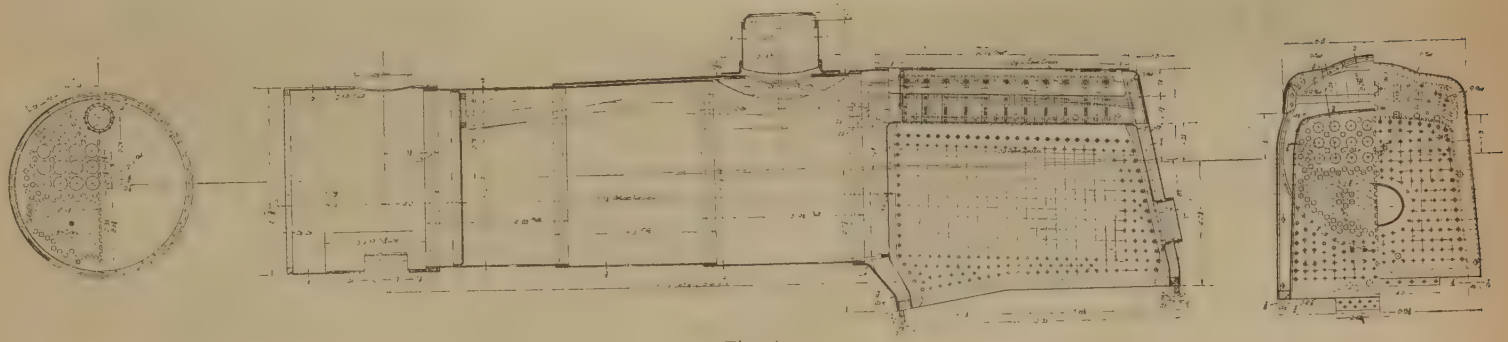


Fig. 4.

Examples of recent design in " Belpaire " boilers are shown in figure 3, illustrating a boiler used on the Pennsylvania Railroad, and figure 4 showing one used on the Canadian Pacific Railway. These drawings also show a boiler barrel of the tapered form illustrated in the two examples of round top fire-box boilers. This form of barrel is not, however, in universal use, as several roads are using barrels of the parallel or straight top type, the courses usually being rolled cylindrically, and varying in diameter by the thickness of the plates alone. The type of barrel used is largely determined by the conditions governing the permissible weight of the boiler, but, with the same limitations as to the water space around the sides of the fire-box, the number of flues that may be placed in a boiler is limited by the diameter of the boiler at the fire-box end, and it is possible for the diameter of the boiler at the front end to be somewhat smaller without affecting this number. A lighter boiler with the same amount of heating surface can thus be obtained than is possible where a parallel form of barrel is used.

On roads on which the weight of the engine is limited by the weight per axle the additional weight entailed at the front end of the engine by the use of a straight or parallel barrel makes but little difference, but, where the weight of the engine is limited by the strength of the bridges over which it has to run, which is usually the case, the tapered boiler barrel has enabled the weight of a boiler with a given heating surface to be somewhat reduced, and it is consequently in general use. This question has also been affected by the tendency to increase the distance between the flues, and the amount of water space between the inner and outer fire-box sheets at the sides. The latter especially has been an important factor in the more extended use of the tapered barrel, as with a small water space the saving in weight obtained by reducing the diameter of the barrel at the front end would not be as great as is the case with the wider spacing in recent use.

The extensive use of the round top fire-box is explained by the results obtained from it being on the whole satisfactory. The " Belpaire " form of box has no doubt an advantage in the fact that the stresses in the various plates and stays can be accurately determined by calculation, whereas in the round top boiler, especially one of the radial stayed type, these stresses cannot be determined with the same degree of accuracy. The service, however, of many thousands of round top boilers has fully demonstrated the safety of this type when properly constructed and maintained, and has proved the correctness of the calculations by which their strength is determined. The " Belpaire " fire-box is somewhat more expensive to construct than the round top, and adds a certain amount to the weight of the boiler without a corresponding increase in the heating surface; hence the largely preponderating use of the simpler round top type.

Although the round top type has proven entirely safe and somewhat cheaper to construct than the " Belpaire ", it is open to question whether its extensive adoption is justified from the stand point of cost of maintenance.

The " Belpaire " fire-box has given a certain amount of trouble not found in the

other type by the cracking of the throat sheet in the O. G. shaped portion between the upper corners of the fire-box and the boiler barrel. The cause of this is not entirely plain, but is possibly due to the connection between the fire-box and the barrel of the boiler, in the ordinary type of "Belpaire", being rigid only at the points where the straight or curved sides and top of the fire-box joint directly to the barrel. This weakness has been remedied in the design shown in figure 3, in which it will be noticed that the sides of the fire-box are curved to conform to the shape of the barrel for a considerable distance, and figure 4, in which the same arrangement has been extended to both top and sides, so that the connection at this point has been considerably strengthened, and experience shows that this difficulty has been to a large extent overcome.

With this exception the maintenance of "Belpaire" fire-boxes has been less than that on round top types, on account of the more equal distribution of the stresses. In the round top radial stayed type the staybolts at the upper corners of the inside fire-box are required to transmit a considerable strain in a horizontal direction through the crown sheet, in order to prevent the outer fire-box sheet from moving outward on account of the pressure in the boiler, and in fact there is little doubt that a certain amount of movement outwards occurs. This has lead to a considerable breakage of staybolts along the upper rows of the fire-box, and consequently to the introduction of staybolts of a flexible type which can accommodate themselves more freely to the relative movement of the inner and outer fire-box sheets. There is little doubt, from the experience obtained on a large number of engines, that the "Belpaire" boiler, especially in bad water districts, is more free from breakage of staybolts than the round top boiler and there is a certain amount of evidence to show that better service is also obtained from the inner fire-box sheets. While therefore the common use of the round top fire-box is justified from the point of view of first cost and safety, the use of the "Belpaire" fire-box may also be justified, at any rate on districts where the water is of poor quality, from the point of view of the lower cost of maintenance.

The boilers illustrated in figures 1, 2, 3 and 4, have the usual type of fire-box employed for bituminus coal on large modern engines. This fire-box is from five feet to six feet wide, and extends over the frames, and, excepting on engines on which the fire-box is placed back of the driving wheels, over the driving wheels. The grate area varies with the size of the boiler, but is usually from forty five to fifty five square feet. Where anthracite coal is used the "Wooten" type of fire-box is generally employed, and figure 5 shows a boiler recently built by the Central Railroad of New Jersey. This design of boiler affords a large area of grate surface and admits of small grades of anthracite coal being burnt at the rate necessary for locomotive service. The fire-box of these boilers is radially stayed, and owing to its form, a certain amount of difficulty has been experienced with the breakage of staybolts, and flexible bolts are therefore employed quite largely in its construction.

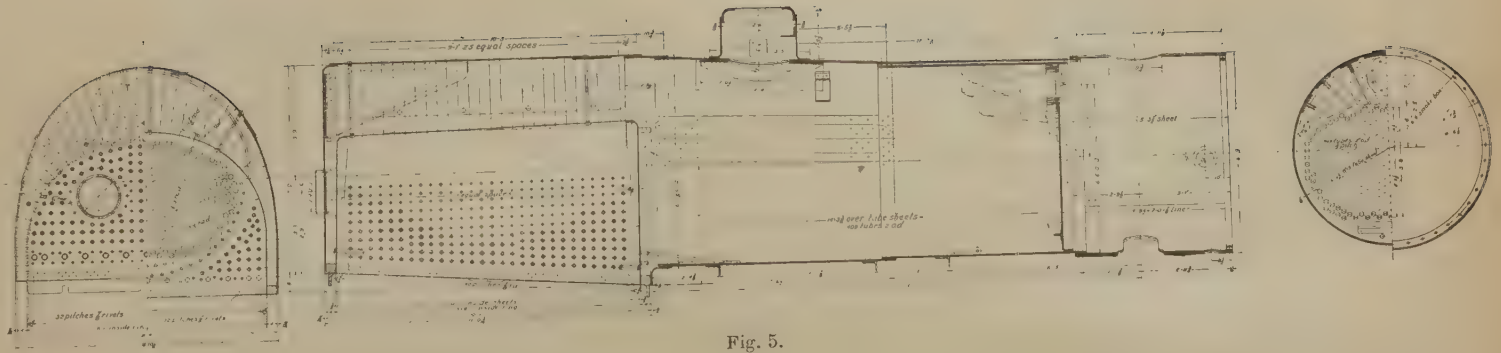


Fig. 5.

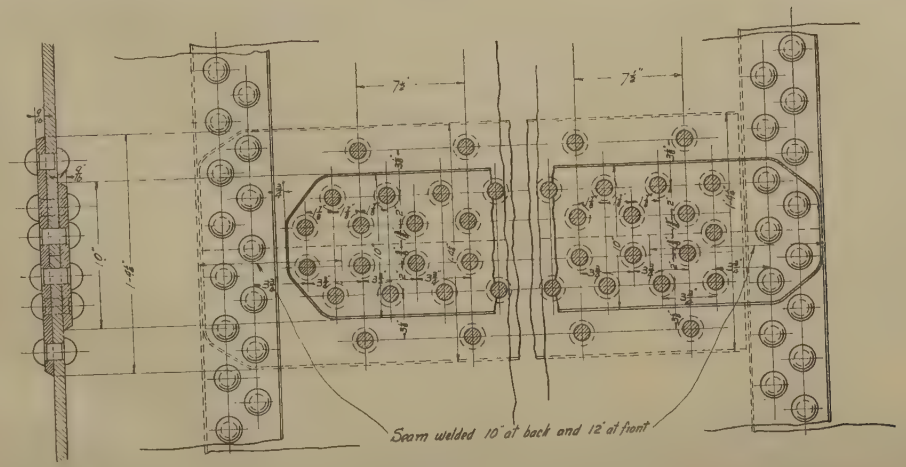


Fig. 6.

1 1/8 inch rivets; 1 3/16 inch holes.

Boiler seams. — The longitudinal boiler seam in general use is shown in figure 6. It is of the triple rivetted butt joint design with inner and outer welt plates, the outer welt plate being narrower than the inner. This joint has a calculated efficiency of about 85 per cent and has proven satisfactory, especially with respect to the avoidance of the grooving which occurs in boiler plates along the edges of the welt plates. A number of administrations have adopted the practice of welding the boiler plates together for nine inches at the end of each seam. This practice has been introduced to avoid the necessity for caulking or plugging the ends of the seam between the boiler plates themselves, which project beyond the ends of the outer welt plate and enables the seam to be made perfectly tight by caulking the edges of the outer welt plate and the rivet heads on the outside of the seam. The administrations using this practice report it as satisfactory and while it is not universal it is becoming general.

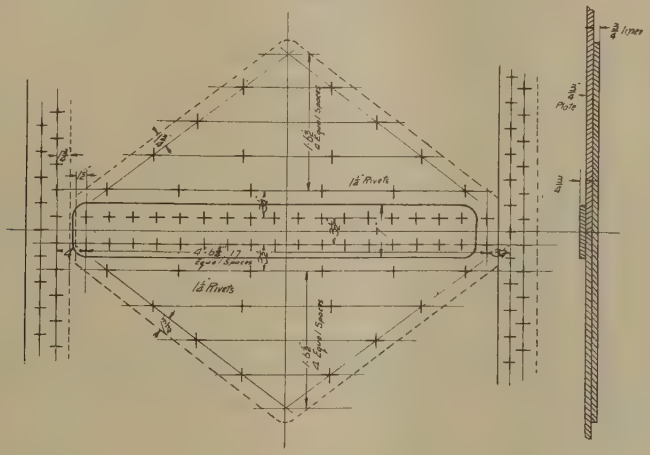


Fig. 7.

The seam shown in figure 7, which is known as the diamond pattern of seam, is used by some administrations. This seam has an exceedingly high efficiency, about 95 per cent, but owing to its being a patented seam it is not in general use. The circumferential seam which is in universal use is a double rivetted lap seam as shown in figure 8, and this seam is also used for the joints between the throat sheet and the barrel, and the outside fire-box sheet and the back sheet of the boiler.

Mud rings. — Mud rings are almost universally double rivetted, two administrations in the United States and one in South America alone reporting a preference for single rivetting, and in those cases additional rivetting is shown at the fire-box corners. The usual practice is shown in figure 9, which shows a double rivetted

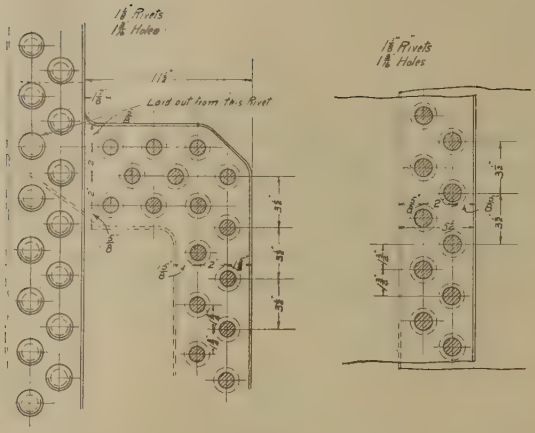

1⅛" Rivets
1⅛ Holes
Laid out from this Rivet
1⅛" Rivets
1⅛ Holes

Fig. 8.

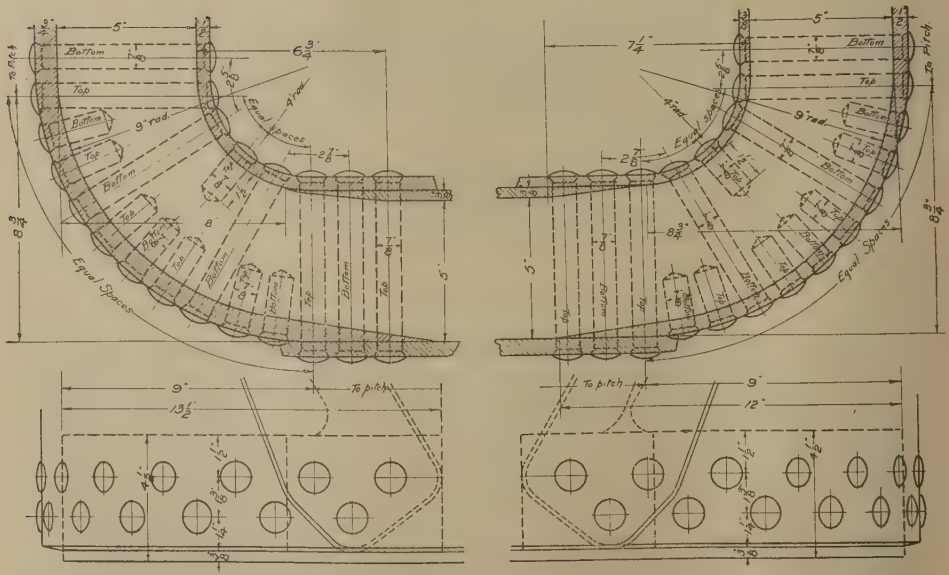
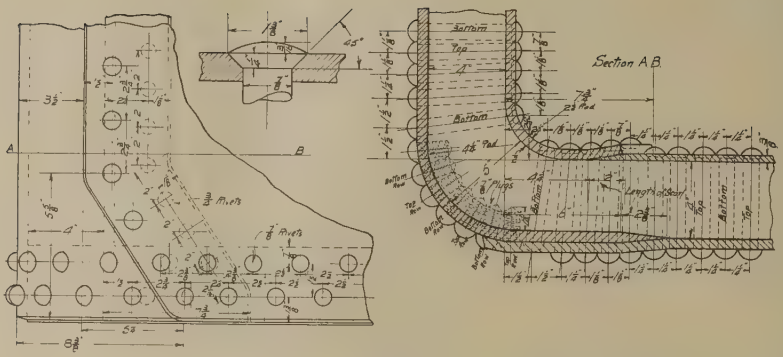

Bottom
Top
9" rad.
4" rad.
Equal Spaces
To pitch

Fig. 9.

mud ring corner, in which a portion of the fastenings of the outside sheet to the mud ring is provided by means of tap bolts, the remaining fastenings being by rivets through both inside and outside fire-box sheets. This design is used by the majority of administrations replying, but a few employ the design shown in figure 10, in which the fastenings at the corner are entirely tap bolts, the through rivets being omitted. One administration prefers the design shown in figure 11, in which the fire-box corners are triple rivetted, the remainder of the rivetting through mud ring being of the ordinary double rivetted style. There is no doubt that a certain amount of difficulty is experienced in obtaining a permanently steam tight joint at the front corners of the fire-box, and the triple rivetted design shown assists in overcoming this difficulty, on account of the short length of rivets used at that point.

Boiler domes. — The connection between the dome and the boiler barrel in universal use is shown in figures 1 and 4, and consists of a heavy flanged collar on the outside of the boiler and a reinforcing plate on the inside. This connection has proven entirely satisfactory and has practically superceded all other designs. The dome barrel is rivetted into this collar and to the top flange. This is usually of pressed steel although cast steel is occasionally used. In some cases the plate forming the body of the dome is welded in place of being rivetted, and the administrations using this practice report satisfactory results. A modification which varies slightly from this design is shown in the drawing of the boiler used by the Pennsylvania Railroad, figure 3. In this case the entire dome is of pressed steel, the collar joining the dome to the boiler barrel and the flange at the top being in one piece. While this design is evidently exceedingly satisfactory, it is not in general favor with locomotive builders who are constructing engines for a number of different roads, and to whom the built up design of dome is preferable on account of their being able to use the same flange blocks for varying heights of domes without expensive alterations.

Boiler staying. — Boiler staying is either of the gusset plate type shown in figures 1 and 5 or the rod type indicated in figures 3 and 4, detail of the usual design of rod staying being shown in figure 12. Administrations replying indicate on the whole a preference for rod staying, and those having experience with both styles prefer the rod stays to the gusset plates. The rods are both cheaper to instal and easier to repair, the strain on the stay can be more accurately adjusted, and any defects which may occur more easily detected. The gusset plates have been found in some cases to loosen and crack with age, and should such cracks occur through the rivet holes in the gusset plates they are hidden, and can only be detected by a most careful inspection. These defects are probably caused by the gusset plates not being applied in such a way as to ensure the rivets being strained to an equal amount, but as this is difficult in practice, there seems to be no doubt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that the rod staying is actually preferable, both on account of its being possible to cause it to bear its proper portion of strain and the greater ease with which it can be inspected and maintained.

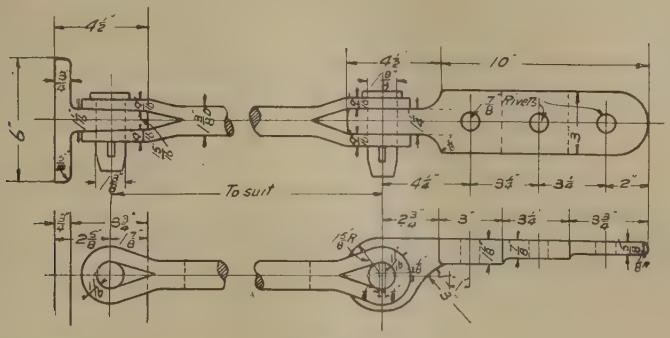


Fig. 12.

Fire-box staying. — The administrations using the round top fire-box construction employ almost universally the direct radial stay for fire-box crown stays, with the exception of the first few rows, which are usually sling stays of various types. The number of rows of sling stays varies with different administrations, but, while some use two or three rows usually the first four front rows are of this construction. The majority of administrations use button headed stays screwed into the fire-box sheet from the inside of the fire-box for the six or eight center rows of radial stays. This general arrangement is shown in figure 13, which shows eight

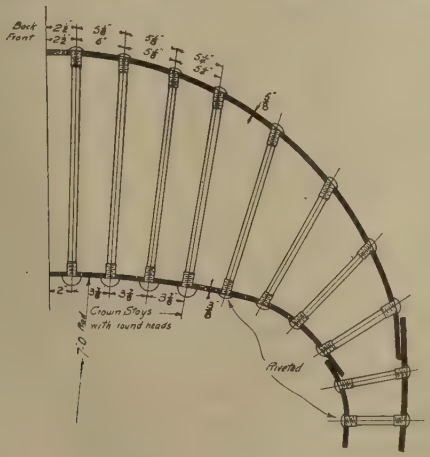


Fig. 13.

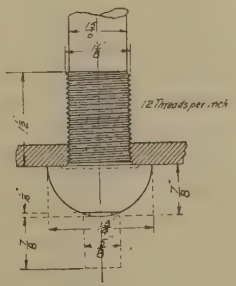
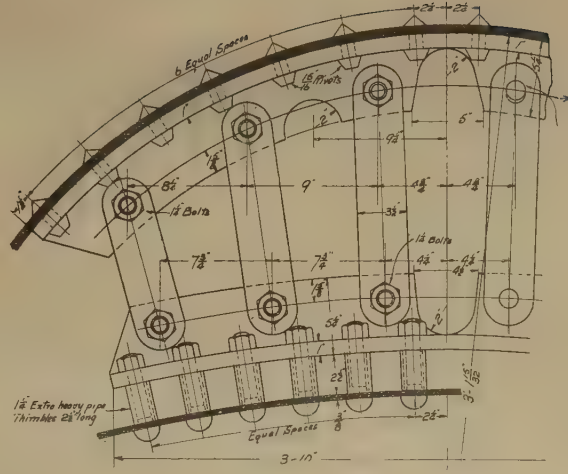


Fig. 14.

rows of button headed stays in the center, and ordinary radial stays for the rows on either side. Figure 14, shows the form of buttonhead usually used on the central rows of stays, the part next the fire-box sheet being recessed near the center, so as to force the head of the stay to bear tightly against the sheet on its outer edges, in order to allow of its being more easily caulked and kept tight. This construction has largely superceded the rivetted head stay, and the type common in " Belpaire " boilers in which a nut is used underneath the fire-box crown sheet in order to provide greater strength than is given by the ordinary rivet head.

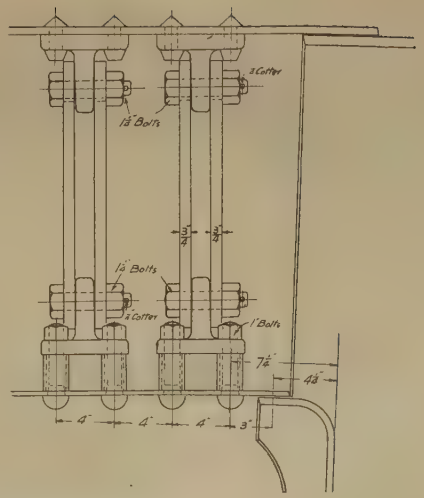
The form of sling or expansion stays in use for the front rows of staybolts are shown in figures 15, 16 and 17. Figure 15 shows a T iron sling stay which is in very general use. Figures 16 and 17 show sling stays employing an eye bolt on the portions rivetted into the fire-box crown sheet and outside fire-box sheet, which are respectively connected by two bars or welded rods forming a link between the top and bottom bolts. A type of expansion stay has also recently been introduced which simply consists of a flexible staybolt rivetted into the fire-box crown sheet. In some cases these designs are modified to permit of the use of a button head on the side underneath the fire-box crown sheet, or nuts are used in order to furnish additional strength. The button head construction has about twice the strength of the ordinary rivet head stay when heated to a dull red heat, and it has been found that when the crown sheet becomes overheated through an absence of water, that, if the center rows of stays are of the button head or nut construction through out, they do not give way until the crown sheet is heated to such a high temperature, that, when failure finally occurs, the sheet is liable to be forced down from end to end. Such an explosion is serious and has torn the boiler apart from the frames and caused serious damage. By using rivetted heads for the front four rows, which are in modern boilers, with sloping top fire-boxes, the highest part of the fire-box and in a location which is overheated before the remainder of the crown sheet is uncovered, these rows will give way before the button heads or nutted stays supporting the remainder of the sheet are overheated sufficiently to seriously affect their strength. They thus act to a certain extent in the same way as a fusible plug and by allowing the steam and water to escape into the fire-box and put out the fire, prevent serious damage occurring.

The universal use of sling or expansion stays for the front rows is largely due to their having been found to reduce the tendency of the flue sheet to crack along the root of the upper flange. Considerable upward movement has been found to occur in the crown sheet of the fire-box with reference to the outer fire-box sheet as the boiler is being heated. No upward movement could of course occur when the crown sheet is exposed to the boiler pressure, as it is not of sufficient strength to sustain this pressure without the load being taken by the stays, but while the water in the boiler is being heated, the pressure on the crown sheet is comparatively small, while the inside fire-box and the outer sheets of the boiler may not be of the



Note. — In applying links cars must be taken to see that the upper end of links bear on bolts on the top side of hole as shown, to insure the proper proportion of load being carried on each link.

Fig. 15.



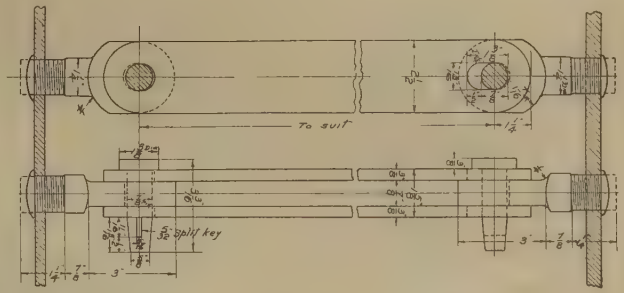


Fig. 16.

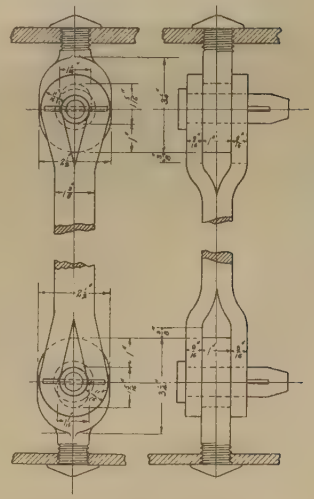


Fig. 17.

same temperature, and if the connections are rigid and relative movement is not permitted, the crown sheet and flue sheet may be forced to bend.

The ordinary crown bar construction supported from the sides or ends of the fire-box is practically obsolete on new construction. A modification of this arrangement is shown in figure 2 and in detail in figure 18. This arrangement is used

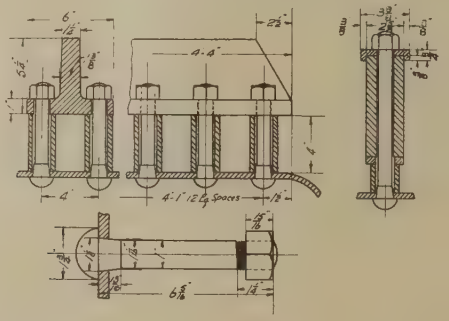


Fig. 18.

on the boilers of the Union Pacific Railroad and is standard on the Harriman Lines. It will be noticed that the front crown stay angle irons are connected to the sides of the boilers by links which provide the necessary staying to prevent the sides of the outer fire-box moving outwards under boiler pressure. Behind these horizontal stay rods are provided for the same purpose, and this arrangement thus closely resembles the " Belpaire " method of staying, with the exception that flat surfaces are not used, and crown bar construction is used in place of the staying of the " Belpaire " type. In figure 18 the construction of the crown sheet stays is shown from which it will be seen that the stays have a taper fit in the crown sheet while the head of the stay is pressed tight against the sheet, a collar being used between the crown bar and the sheet in order to keep it in place. This construction is not a usual one in the United States, although the administrations using it control a large number of locomotives. The administrations using radial stays combined with various designs of expansion stays for the front rows, report that their use is satisfactory and that they are preferable to crown stays which have of course been in extensive use on boilers of an older type. The Buenos Ayres & Rosario Railway report that they have both in use but prefer the crown staying construction as with radial stays cracking occurs along the top flange of the flue sheet whereas with crown stays it does not. The general preference for radial stays in the United States must be ascribed to its being possible to keep the crown sheet free from scale with this form of staying whereas with the crown bar arrangement it is practically impossible to do so unless the water used is exceedingly good.

Inside fire-boxes. — Inside fire-boxes in the United States are universally of steel, and with very few exceptions the crown sheet, side sheet and back sheet are $^{5}/_{8}$ inch in thickness. A few of the administrations use $^{7}/_{16}$ or $^{1}/_{2}$ inch crown sheets but their number is small and the use of $^{3}/_{8}$ inch for these sheets may be stated to be almost universal. Side sheets are occasionally $^{5}/_{16}$ inch in thickness, and some of the administrations using this thickness prefer it to $^{3}/_{8}$ inch, and state that less trouble is experienced with the thinner sheet. The same remarks apply to the back sheet of fire-box but in both cases it may be stated that the use of $^{3}/_{8}$ inch plate is almost universal. The tube sheets are almost universally $^{1}/_{2}$ inch in thickness, although in some cases $^{5}/_{8}$ inch sheets are used for pressures above 180 pounds. The majority of administrations replying have made no increase in the thickness of their fire-box sheets for pressures of from 180 to 200 pounds, and report that no change is necessary. The Buenos Ayres & Rosario Railway using a copper fire-box report the use of $^{1}/_{2}$ inch copper sheets for the crown, back and side sheets, and $^{7}/_{8}$ inch or 1 inch for flue sheets, but they have made no difference in the case of boilers carrying higher pressures. The design of inside fire-box is shown in the various illustrations and calls for no special reference. The seams are invariably single rivetted lap seams, rivets being usually $^{3}/_{4}$ inch in diameter and 1-$^{7}/_{8}$ inches to 2 inches pitch The lap of the seam is made as small as possible and is usually 2 inches, although in some cases 2-$^{1}/_{4}$ inches is used. This seam is shown in figure 19.

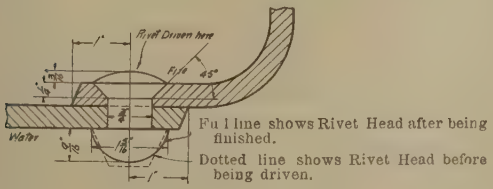

Rivet Driven here
45°
Water
Full line shows Rivet Head after being finished.
Dotted line shows Rivet Head before being driven.

Fig. 19.

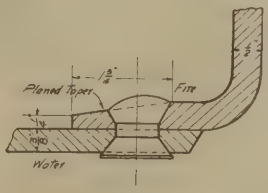


Fig. 20.

While not universal, the practice of reducing the thickness of the flue sheet at the seam is adopted by a number of administrations. In some cases the thickness of the back sheet at the seam is similarly reduced. This arrangement is shown in figure 20 and it will be seen that the rivets are countersunk in the seam and the thickness of the metal exposed to the fire is reduced as much as possible. Some administrations reduce the seam in this manner from the bottom of the fire-box for from 12 to 24 inches, while others do so for the entire length of the seam. The administrations using this practice report that it has considerably reduced the difficulty previously experienced with plates cracking from the rivet holes to the outer edge of the seam and it may be regarded as good practice. Its necessity is evidently affected by the quality of the water used. Where good water is used cone

head rivets and full thickness plates are found to give but little trouble, but where the water is bad and there is a tendency for the edges of the seam to become overheated, the reduction in the thickness of the plate appears to prevent to a large extent this deterioration and formation or cracks. Reference has been made to cracking of flue sheet along the corner of the upper flange. Figure 21 illustrates the design that has been commonly used for the last few years, in which the radius of the flange is about 2 inches at the upper portion of the tube sheet, and is gradually reduced to about $^3/_4$ inch at the sides where little trouble is experienced. The increase of this radius to 2 inches from $^3/_4$ inch which was previously used is stated by many administrations to have given good results. Two administrations, however, which have used it report that it gives more trouble from cracking than the smaller radius. Opinion is divided on this question, but it is stated that on the whole the increase in the size of this radius has not overcome the difficulty, which is quite a serious one, as a number of sheets crack around the root of the upper flange. The use of a larger radius at this point has necessitated a slight reduction in the number of tubes which can be placed in any boiler, and if it is not found to be advantageous its use will be abandoned. There is not, however, sufficient experience at present to state definitely whether or not this detail of design should be followed.

Fire-box door. — Fire door openings are usually oval in form, 13 inches by 18 inches to 16 inches by 20 inches in size. Some administrations use two doors on wide fire-boxes using bituminus coal. The most common form of connection between the back sheet of the fire-box and the outside back sheet of the boiler is shown in figures 1, 2 and 3. The inside fire-box sheet is flanged outwardly, the outside sheet being flanged inwardly to meet it, forming a single rivetted lap joint. Another form in common use is shown in figure 22, in which both sheets are flanged outwardly, and a collar is used to connect the inner and outer sheets. This type of joint is somewhat easier to construct than the other, and is reported to give very good satisfaction. A modification is shown in figure 23, in which the construction shown in figure 22, is modified by using a solid ring between the collar and outside sheet. This type of door is only reported by one administration, and is not in general use. A patented connection is used by several administrations and is illustrated in figure 24. The form in which the sheets are flanged is stated to give greater flexibility and avoid the cracking of the sheets in the corners of the flanges. The same result is obtained by spacing the staybolts between the back sheets of the inner and outer fire-box at a rather greater distance from the door opening than usual. On the Buenos Ayres & Rosario Railway the inner and outer sheets are connected up by a solid ring of the type common in European practice. This method is not, however, used in the United States where the arrangement shown in figures 1, 2 and 3, is the most general, and that used in figure 22 the usual alternative arrangement.

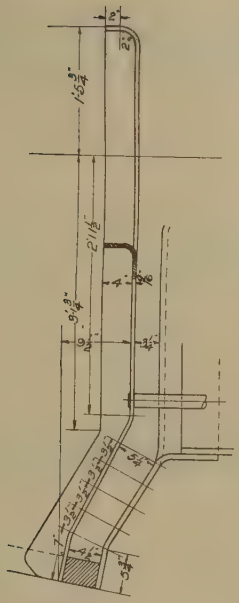


Fig. 21.

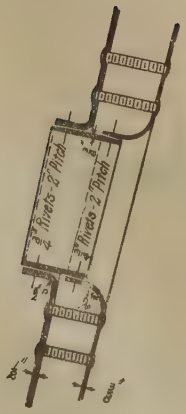


Fig. 22.

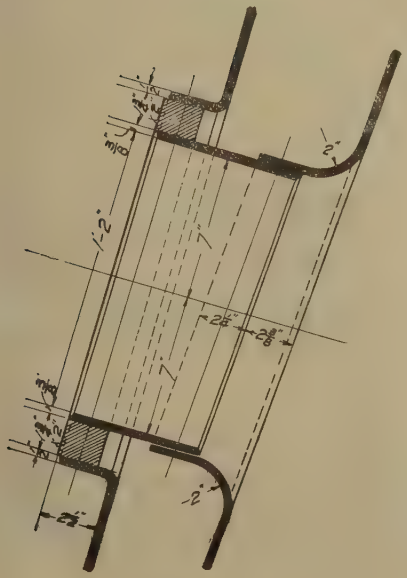


Fig. 23.

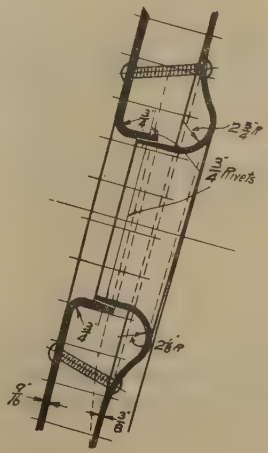


Fig. 24.

Fire-box barrel stays. — Stays from the fire-box tube sheet to the barrel of the boiler are commonly of the type shown in figures 25, 26 and 27, the former being the most common. In figure 25 a threaded stay is used which is rivetted over in

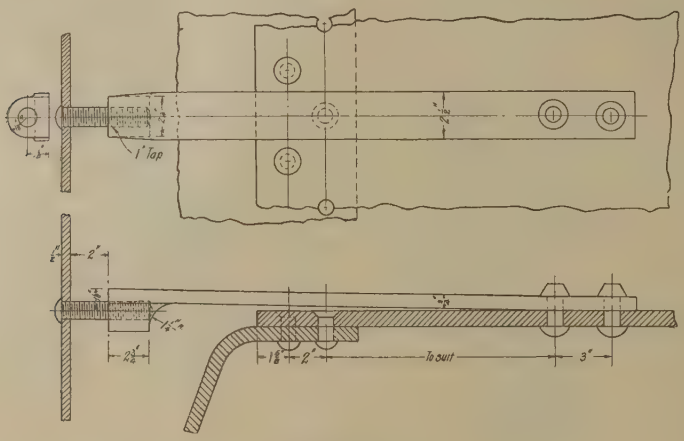


Fig. 25.

the fire-box sheets. Figure 26, shows a design in which bolts are used in place of threaded staybolts to connect the brace and the fire-box sheet. In figure 27 the bolt

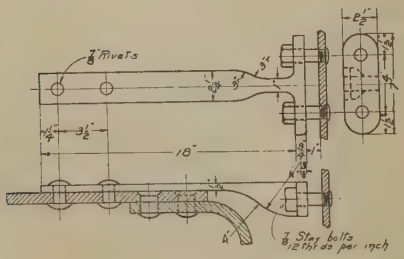


Fig. 26.

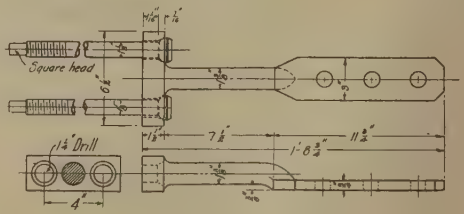


Fig. 27.

threaded in to the fire-box sheet is flexibly connected to the bracket. The Pennsylvania Railroad do not use this type of stay, but by referring to figure 3, it will be seen that the fire-box tube sheet and the throat sheet of the fire-box are formed in such a

way that stays of this description are not required. By an ingenious design the tube sheet is flanged to a curved surface and the throat sheet formed to correspond. While this arrangement is evidently satisfactory it is not as easy to construct from a builders standpoint, as the ordinary design of throat sheet with flat surfaces and is therefore not generally adopted.

Water spaces. — The water spaces between the inner and outer fire-boxes have been considerably increased during the past few years. Instead of water spaces at the mud ring of 3 1/2 inches to 4 inches at the front of the fire-box and 3 inches to 3 1/2 inches at the side and back a number of administrations now use 5 inch water spaces at front, sides and back, while the use of 5 inches at the front and 4 1/2 inches at the sides is common. The water space at the top of the fire-box has also been increased, many administrations using a minimum of 6 inches while in others this figure is made as large as 6 1/2 inches to 7 1/2 inches and even 8 inches. There is no definite information obtainable as to the advantage gained by this increased spacing, but there is a very general opinion that better circulation is obtained and that a decided improvement is obtained in the life of staybolts and fire-box sheets. South American administrations replying, report water spaces of 2 1/2 inches to 3 inches, but this evidently refers to boilers of a smaller capacity than is common in the United States. While the larger water spacing increases to a certain extent the weight of the boiler, as previously mentioned where large spaces are used, the barrel of the boiler is tapered so as to reduce the increase of weight to as great an extent as possible. The spaces between the tubes and the sides and bottom of barrel show a considerable variation in the different designs. This also is a dimension that affects the weight of the boiler but replies received from the various administrations would indicate that it is not generally regarded as important; with the exception of a few isolated cases the minimum dimension between the tubes and the side of the boiler which has been permitted is 2 inches, between the tubes and the bottom of the boiler 2 1/2 inches to 3 inches. These would appear to be satisfactory minimum dimensions, but some administrations indicate a preference for a space of 4 inches to 5 inches. The distance from the top of the fire-box crown to the under side of the outer fire-box sheet of the boiler also varies considerably on different engines, 18 inches being about the minimum figure allowed, while 24 inches is about the maximum. Replies received would indicate that 20 inches to 22 inches is a satisfactory figure at this point.

Staybolts. — Staybolts in the United States and Canada are universally of wrought iron, generally 1 inch in diameter although sizes from 7/8 inch to 1 1/8 inches are used to a certain extent. The outer ends are usually drilled with a 3/16 inch hole 1 1/4 inches deep, for the purpose of indicating by the escape of water any breakage that might occur. In place of the rigid bolt various types of flexible bolts are

frequently substituted, and figure 28, shows a flexible bolt which is in common use, while figure 29, shows a patented type of flexible bolt called the "Tate" which is

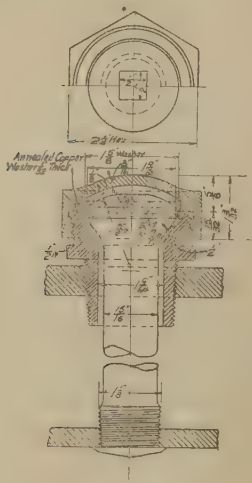


Fig. 28.

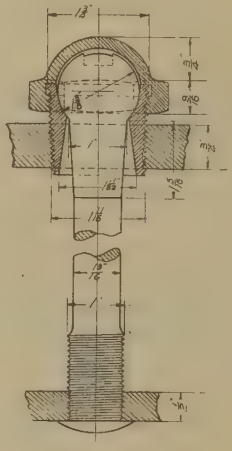


Fig. 29.

also used by a number of administrations replying. The latter possesses the advantage that deposits of scale cannot interfere with its flexibility. Flexible bolts of whatever type are usually applied to fire-boxes at the points where the amount of breakage of staybolts experienced is large. Figure 30, shows a representative appli-

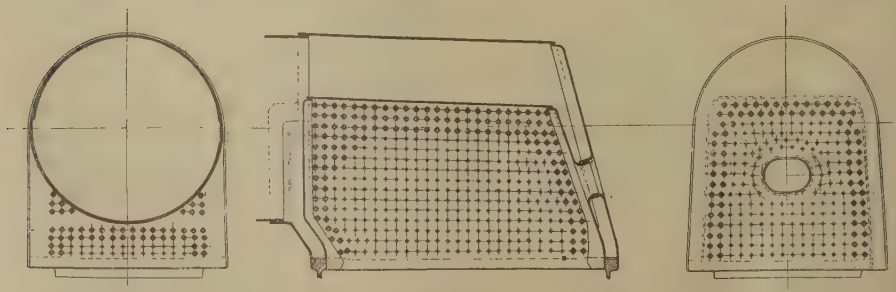


Fig. 30.

cation in which the flexible bolts are disposed along the edges and corners of the fire-box sheets, which are the points where breakage most frequently occurs, and the

number of flexible bolts is usually about thirty to forty per cent of the entire number of staybolts in the fire-box. On "Wooten" fire-boxes the breakage occurs in a different location, *viz.*, for about two feet above the mud ring throughout the entire length of the side sheets, and roads on which this type of boiler is used apply flexible staybolts in that location. While not common practice certain administrations have largely extended the use of this type of bolt. It has given exceedingly good satisfaction so far as freedom from breakages is concerned but on account of its increased cost the question of determining to what extent it is economical to apply them is largely dependent on the service obtained from the ordinary type of bolt. This has been considerably improved by the increase that has taken place in the water space around the fire-box and recent indications would appear to show that while the use of a certain number of flexible staybolts is advisable that the number employed will not be largely increased. In South America where copper fire-boxes are used copper staybolts are alone employed and flexible bolts are consequently not used.

Tubes. — Tubes are usually 2 inches in diameter although some administrations use 2 1/4 inch tubes on large engines while others use 2 1/4 inches when tubes are over 15 to 18 feet in length. Replies would indicate that the use of 2 1/4 inch tubes is usual on long boilers, but that 2 inch tubes have been found satisfactory for lengths of 18 to 20 feet. The tubes are usually 0·12 inches in thickness but a number of administrations report using tubes 0·11 inches in thickness with satisfactory results. The usual spacing center to center for a 2 inch tube is 2 3/4 inches and for 2 1/4 inch flues 3 inches. A number of administrations, especially those operating in districts where the water is not good, have increased the spacing to 2 7/8 inches for 2 inch and 3 1/8 inches for 2 3/4 inches, and report better circulation and improved results. In the front tube sheet the spacing is usually 2 11/16 to 2 3/4 inches for the 2 inch tubes, and a corresponding distance for 2 1/4 inch tubes. No difficulty is experienced with smaller spacing in the front tube sheet, and the weight of the boiler can evidently be somewhat reduced. The tubes are usually disposed in rows that are vertical and incline at 30° to the horizontal. Occasionally two vertical rows of tubes are used in the center, and one administration is using three vertical rows in the center, and three horizontal rows about the middle of the sheet. A few administrations use vertical and horizontal rows only and while these roads are comparatively few in number this arrangement is claimed to give better circulation and tend to keep the tubes cleaner.

Apart from the South American administrations who are using brass tubes the invariable practice is to cut out the tube when the end has been damaged by continual tightening, and subject it to what is termed rattling by rolling it with other tubes in a machine which removes the scale. A piece about 7 inches long is then welded on the original tube to restore it to its proper length. This process is termed safe-ending and is illustrated in figure 31. It will be seen that the body of

the tube is expanded to taper from the inside outwards, while the safe end is tapered rom the outside to the inner edge. The safe end is then welded to the body of the tube and the opposite end of the original tube cut off to length. The hole in the tube sheet is usually made of the same diameter as the tube, *viz.*, 2 inches for 2 inch tubes. The end of the tube is reduced in diameter to $1\ ^7/_8$ inches and a copper ferrule $^1/_{16}$ inch or less in thickness and the same width as the thickness of the tube sheet is placed in the hole in the tube sheet with its edge about $^1/_{16}$ inch below the back surface of the sheet. The ferrule is slightly rolled to hold it in place and the tube inserted until its end projects $^3/_{16}$ inches beyond the sheet within the fire-box. The tube is then rolled in place and its appearance at this stage is shown in figure 32.

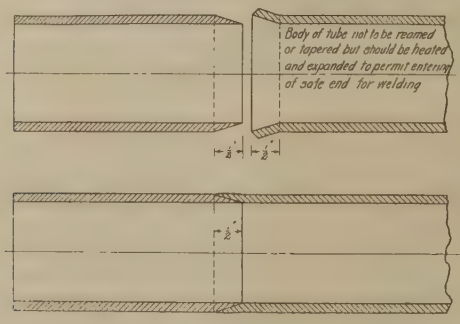


Fig. 31.

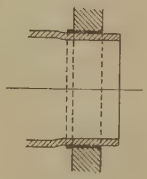


Fig. 32.

The roller expander used is shown in figure 33 of what is frequently termed the *Dudgeon* type. The tube end is next expanded with what is termed a *Prosser* expander, which expands the tube slightly on both sides of the tube sheet driving the projecting end outward and pinching the tube tightly against the sheet on both outside and inside. Its appearance when this operation is completed is shown in figure 34. The tool which does this work is made in sections which are expanded

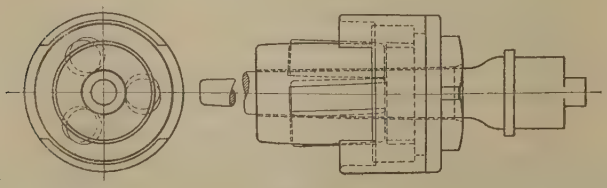


Fig. 33.

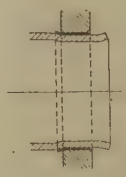


Fig. 34.

by the driving in of a tapered pin and is called the Prosser expander after its inventor. It is shown in figure 35. The end of the tube is next beaded over and its appearance when this is completed is shown in figure 36, which also shows the action of the beading tool. This is shown in detail in figure 37, and the gauge by which the tool

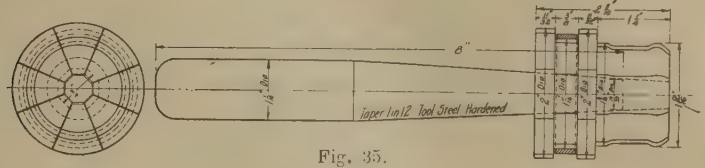


Fig. 35.

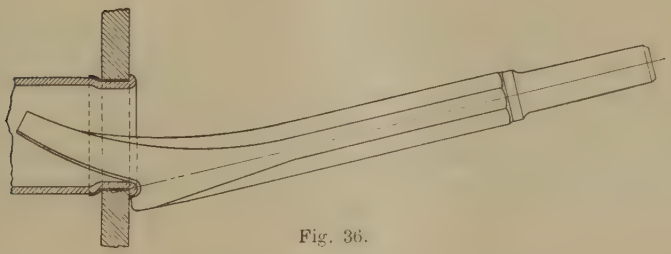


Fig. 36.

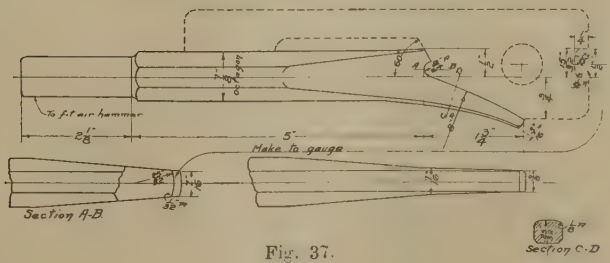


Fig. 37.

is maintained in its proper shape is shown in figure 38. The process illustrated while varying slightly in detail is practically in universal use throughout the United States. The inside shape of the Prosser expander and of the beading tool vary somewhat with different administrations, but with each, the shape of these tools is maintained with the greatest care, as any variation in their form or dimensions, at the various points at which this work is done, will cause serious damage to the ends of the tubes through reducing their thickness unevenly and will materially affect the service they give. At the front end of the boiler no copper ferrules are used. The

hole is usually $^1/_8$ inch larger than the actual diameter of the tube, and the tube is slightly enlarged before being put in, and expanded into the sheet by a roller expander. Some administrations depend entirely upon rolling in the front sheet,

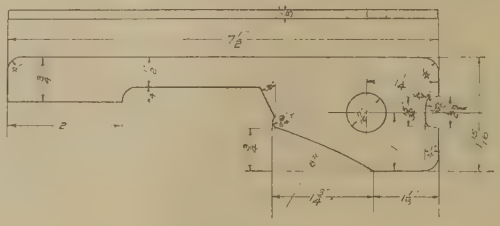


Fig. 38.

others bead twenty per cent of the flues in the front sheet while some bead all flues in the front sheet in addition. The usual practice is to bead a portion of the flues in the front sheet, especially when the boiler pressure is over 180 pounds. In some cases where horizontal and vertical rows of flues are used, these are beaded while those in the remaining rows are simply rolled. No trouble is reported in either case in the front flue sheet and there is no question that flues properly rolled into this sheet furnish ample strength to withstand the strains.

Water gauges. — The use of both gauge cocks and glass water gauges is practically universal. The gauge cocks are located on the right hand side of the back of the

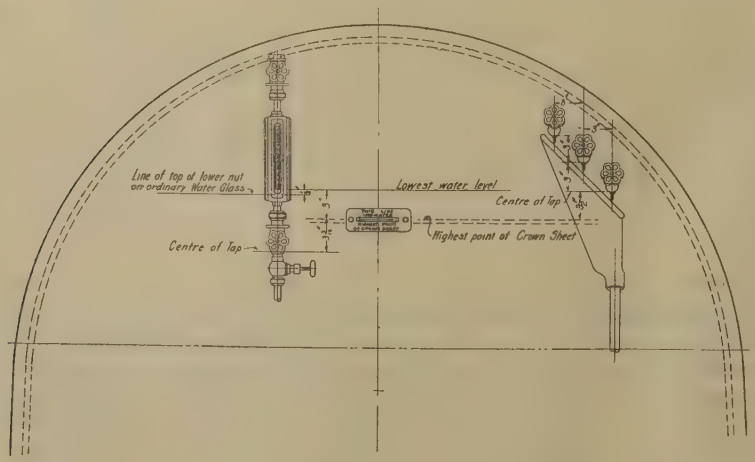

Line of top of lower nut on ordinary Water Glass
Lowest water level
Centre of Top
Centre of Top
Highest point of Crown Sheet

Fig. 39.

boiler where they can be easily reached by the engineer. The glass water gauges are usually placed on the left side, the common arrangement being similar to that shown in figure 39. The distance from fire-box crown sheet to the bottom of gauge cock, which is usually placed on a level with the bottom of the visible portion of the glass water gauge, varies considerably on different roads. The smallest figure reported is 2 $^1/_2$ inches and the greatest 7 inches. General practice would indicate that this figure should not be less than 3 inches while many administrations prefer 3 $^1/_2$ inches or 4 inches. The gauge cocks are usually three in number the distance from center of bottom to top gauge cock being very generally 6 inches. The visible portion of the glass water gauge is very generally 8 to 9 inches in length, the tendency being to reduce this and a length of 7 inches is in common use. In place of glass tubes, various designs of reflex gauges are extensively used having an opening of 6 $^1/_2$ inches to 8 inches. It may be stated that the water is visible in the gauge glass at from 3 to 4 inches above the crown sheet while with the gauge glass full of water the depth of water is from 10 to 11 inches.

Boiler and fire-box material. — The plates of the shell of the boiler are almost universally obtained to specification, while those for the fire-box, in addition to conforming to specification, are frequently required to be furnished by certain makers. The specifications in use follow very closely those of the American Railway Master Mechanics Association extracts from which are as follows :

1. *Special requirements for shell sheets.*

This grade of steel is known to the trade as flange or boiler steel. The desired tensile strength is 60,000 pounds per square inch, with minimum and maximum limits 55,000 and 65,000 pounds. The elongation in 8 inches shall not be less than 25 per cent for sheets three quarters of an inch thick or under. For thicker sheets, deduct 1 per cent from specified elongation for each one eighth inch additional thickness.

2. *Chemical requirements for shell sheets.*

Phosphorous shall not exceed (acid)	0·06 per cent.
Phosphorous shall not exceed (basic)	0·04 —
Sulphur shall not exceed.	0·05 —
Manganese	0·30 to 0 60 —

3. *Special requirements for fire-box steel.*

The desired tensile strength is 57,000 pounds per square inch, with minimum and maximum limits 52,000 and 62,000 pounds. The elongation in 8 inches shall not be less than 26 per cent.

4. Chemical requirements for fire-box sheets.

Carbon	0·15 to 0·25	per cent.
Phosphorous shall not exceed (acid)	0·04	—
Phosphorous shall not exceed (basic)	0·03	—
Sulphur shall not exceed	0·04	—
Manganese	0·30 to 0·50	—

GENERAL REQUIREMENTS.

5. Bending tests.

Test specimens for this purpose shall be 1 1/2 inches wide, and for material 3/4 inch or less in thickness shall be of the same thickness as that of the finished sheet. For sheets more than 3/4 inch thick the bending test specimen may be 1/2 inch thick. The sheared edges of bending test specimens may be milled or planed. The cold bending test shall be made on material in the condition in which it is to be used. The specimen for quench bending test shall be heated to a light cherry red, as seen in the dark, and quenched in water having a temperature between 80° and 90° Fahr. Boiler steel and fire-box steel, before and after quenching, shall bend cold 180° flat on itself without fracture on the outside of the bent portion. The bending test may be made by pressure or by blows. One cold bending specimen and one quenched bending specimen will be furnished from each plate as it is rolled. The homogeneity tests for fire-box steel shall be made on one of the broken tensile specimens.

6. Specimens for tensile test.

Two tensile test specimens will be furnished from each plate as it is rolled. The standard test specimen of 8 inch gauged length shall be used for the tensile test.

7. Homogeneity test.

The homogeneity test for fire-box steel is made as follows : A portion of the broken tensile test specimen is either nicked with a chisel or grooved on a machine, transversely about an sixteenth of an inch deep, in three places about two inches apart. The first groove should be made on one side, two inches from the square end of the specimen ; the second, two inches from it on the opposite side, and the third, two inches from the last and on the opposite side from it. The test specimen is then put in a vise, with the first groove about a quarter of an inch above the jaws, care being taken to hold it firmly. The projecting end of the test specimen is then broken off by means of a hammer, a number of light blows

being used, and the bending being away from the groove. The specimen is broken at the other two grooves in the same way. The object of this treatment is to open and render visible to the eye any seams due to failure to weld up, or to foreign interposed matter, or cavities due to gas bubbles in the ingot. After rupture, one side of each fracture is examined, a pocket lens being used if necessary, and the length of the seams and cavities is determined. The broken specimen shall not show any single seam or cavity more than $^1/_4$ inch long in either of the three fractures.

A number of administrations specify that plates which are used for throat sheets, dome collars or which undergo severe flanging shall be furnished to fire-box steel specifications. The specification for methods of inspection, variations in weight, etc., vary considerably but otherwise the more important variations from the above specifications are as follows : The Pennsylvania, Baltimore & Ohio and Southern Railways, specify that the elongation for boiler plates shall equal 14,000,000 divided by the tensile strength in pounds, and do not reject plates for high tensile strength if the elongation is over 28 per cent. These roads also desire that the plates shall contain 0·03 per cent copper. Several administrations in place of allowing a different amount of phosphorous in basic and acid steel simply specify that the amount of phosphorous shall not exceed 0·05 per cent. The Pennsylvania Railroad specify for fire-box steel a tensile strength of between 55,000 and 65,000 pounds per square inch with an elongation equal to 14,500,000 divided by the tensile strength in pounds. The Baltimore & Ohio Railroad specify a tensile strength of between 48,000 and 58,000 pounds per square inch with the same elongation. A number of administrations specify for fire-box sheets that the sulphur shall not exceed 0·035 per cent. The Pennsylvania, Baltimore & Ohio and several other large administrations also specify that the manganese shall not exceed 0·45 per cent or the silicon 0·03 per cent. The Pennsylvania Railroad desires that the plates shall contain 0·03 per cent of copper but reject if they contain more than 0·05 per cent. The Baltimore & Ohio Railroad desire that the plate shall contain 0·02 per cent of copper but reject if they contain more than 0·03 per cent, In general, however, it may be stated that the specifications of the American Railway Master Mechanics Association represent the average material specified for use in boiler steel. There is a tendency to use steel either slightly softer, or slightly harder than that specified by the Association for fire-box plates and also to insist on the sulphur and phosphorous content being somewhat below that mentioned. Many specifications specify that the steel desired for fire-box plates is the best that can be made by modern methods and the various specifications are evidently drawn with this end in view.

Tube material. — For many years charcoal iron has been considered the best material for boiler tubes. Seamless steel is now extensively used, and is considered by many preferable for that portion of the tube which is inserted into the tube sheet, as it is found to give longer life before renewal is required. A number of adminis-

trations replying express a preference for the lap welded charcoal iron tube, while others consider charcoal iron tubes resist pitting better than steel tubes but do not last as long in the tube sheet. Some administrations use a tube of charcoal iron but weld to it a seamless steel end, and where trouble is experienced by the water attacking the body of the tube this would apparently be the best practice. Usually the same material is used for the body of the tube and for the safe ends which are welded to it, after it has been removed from the boiler, in order to restore it to its original length. In some cases, however, the safe ends is made of greater thickness than the body of the tube, usually 0·135 inch, and two large administrations apply steel safe ends to new wrought iron tubes before placing them in the boiler.

In order to determine the quality of the material some administrations depend entirely upsn the brand, others entirely on the specification while a combination of the two is in general practice. Specifications employed are usually similar to those of the American Railway Master Mechanics Association which are as follows :

Specifications for iron locomotive boiler tubes.

1. Tubes are to be made of knobbed, hammered charcoal iron, lapwelded.

2. Tubes must be of uniform thickness throughout, except at weld where an additionnal thickness of 0·015 will be allowed. They must be circular within 0·02 inches, and the mean diameter must be within 0·015 inch of the size ordered. They must be within 0 01 inch of the thickness specified and not less than the length ordered, but may exceed this by 0·125 inch.

Surface inspection

4. Tubes must have smooth surface, free from all laminations, cracks, blister, pits and imperfect welds. They must be free from bends, kinks and buckles, and from evidence of unequal contraction in cooling or injury in manipulation.

Physical tests.

5. *Bending tests.* — Strips $^1/_2$ inch in width by 6 inches in length, planed lengthwise from tubes, after having been heated to a cherry red and quenched in water at 80° Fahr. shall bend in opposite directions at each end, without cracks or flaws and when nicked and brocken by slight blows, these strips must show a fracture wholly fibrous.

6. *Expanding test.* — Sections of tubes 12 inches long shall be heated a length of 5 inches to a bright cherry red in daylight and then placed in a vertical position and a smooth taper steel pin at blue heat will be driven into the end of the tube by light blows of a 10 pound hammer. Under this test the tube must stretch to 1 $^1/_8$ times its original diameter without splitting or cracking. The pin used shall be of tool steel tapered 1 $^1/_2$ inches to the foot.

In making this test, care must be taken to see that the end of the tube is smoothly trimmed.

7. One tube is to be tested, as required in paragraphs 5 and 6, in each lot of 250 tubes or less.

8. *Crushing test.* — A section of tube 2 1/2 inches long, when placed vertically on the anvil of a steam hammer and subjected to a series of light blows, must crush to a height of 1 1/8 inches without splitting in either direction and without cracking or bending at weld.

9. *Hydraulic test.* — Before shipping, each tube must be tested by manufacturer to 500 pounds per square inch, and each tube must be plainly marked in the middle : " Knobbled charcoal, tested to 500 pounds pressure ".

10. In addition to the above tests, tubes which, when inserted into boilers, split or break while being expanded or beaded, and also individual tubes which fail to pass surface inspection will be rejected and returned to the maker at their expense.

11. *Etching test.* — In case of doubt as to the quality of the material, the following test shall be made to detect the presence of steel. A section of tube, turned or ground to a perfectly true surface on the end, will be polished free from dirt or cracks, and the end of the tube will be suspended in a bath of nine parts water, three parts sulphuric acid and one part hydrochloric acid. The bath will be prepared by placing water in a porcelain dish, adding the sulphuric and then the hydrochloric acid. The chemical action must be allowed to continue until the soft parts are sufficiently dissolved so that the iron tube will show a decided ridged surface, with the weld very distinct, while the steel tube will show a homogeneous surface.

Specifications for seamless, cold drawn steel locomotive boiler tubes.

1. *Tubes are to be cold drawn, seamless and made of open hearth steel.* — It is desired that the steel from which the tubes are manufactured should have the following chemical composition :

Carbon.	0·15 to 0·20 p. c.
Manganese	0·45 to 0·55 —
Sulphur, below.	0·05 —
Phosphorus, below	0·05 —

Tubes containing more than 0·05 phosphorous or sulphur whil be rejected.

2. *Tubes must be of uniform thickness throughout.* — They must be circular within 0·02 of an inch and the mean diameter must be within 0·015 inch of the size ordered. They must be within 0·01 inch of the thickness specified and not less than the length ordered, but may exceed this by 0·125 inch. They must be free from bends, kinks and buckles.

Physical Tests.

4. *Bending test.* — Strips 1/2 inch in width by 6 inches in length, planed lengthwise from tubes, after having been heated to a cherry red and quenched in water at 80° Fahr, shall

bend in opposite directions at each end, as shown in sketch below without cracks or flaws.

5. *Expanding test.* — Sections of tubes 12 inches long shall be heated a length of five inches to a bright cherry red in daylight and then placed in a vertical position and a smooth taper steel pin at blue heat will be driven into the end of the tube by light blows of a 10 pound hammer. Under this test the tube must stretch to 1 1/8 times its original diameter without splitting or cracking. The pin used shall be of tool steel tapered 1 1/2 inches to the foot. In making this test care must be taken to see that the end of the tube is smoothly trimmed.

6. *Crushing test.* — A section of tube 2 1/2 inches long, when placed vertically on the anvil of a steam hammer, and subjected to a series of light blows, must crush to a height of 1 1/8 inches without splitting in either direction.

7. *Flattening test.* — A test piece of tube 6 inches long, when flattened lengthwise cold until the sides are separated by a distance equal to the gauge of the tube, must not show any splits or cracks.

8. One tube is to be tested as required in paragraphs 4, 5, 6 and 7 in each lot of 250 tubes, or less.

9. Each tube must be subjected by the manufacturer to an internal pressure of 1,000 pounds to the square inch and must be plainly stenciled Seamless Steel Tubes, tested to 1,000 pounds.

It is unusual to adopt these specifications in their entirety and the expanding test, in paragraph 6 of specification for iron locomotive boiler tubes, is frequently omitted. Several administrations also use a crushing test similar to paragraph 8 in specification for iron locomotive boiler tubes, but employ a section of tube 1 1/4 inches long, which when flattened down solid must show but slight cracks for iron tubes, and no cracks whatever for steel. Direct tensile tests are seldom used, but one administration specifies a tensile strength lengthways of the tube of 48,000 pounds per square inch, and an elongation of 20 per cent in 2 inches. Another large administration uses a special test in which the tubes are forced cold over a steel tapered plug, and must expand to 1·3 times their original diameter without splitting, but in general there is a tendency to simplify specifications for wrought iron tubes, and with seamless steel tubes, on account of the uniformly high quality of the material required to withstand the drawing process, there is a tendency to accept tubes made by a reliable manufacturer without extensive specifications.

Staybolt material. — The quality of the iron used is in most cases determined by the brand. On account of the continual bending strains which staybolts are subjected to, by the relative movement which ocurs between the inner and outer fire-box sheets, the structure of the iron is at least equal in importance to its physical

properties, and, with the exception of a few administrations, specifications are not used to determine whether any make of iron is acceptable or not, but are used in connection with the brand as a safe guard. One administration which depends upon specifications, expresses the opinion that the make of iron should also be taken into consideration, thus confirming the opinion that the method of manufacture is an important factor in the life of the stays. Where specifications are used, the usual requirements are a tensile strength of from 48,000 to 52,000 pounds, with an elongation of twenty eight per cent in 8 inches. In some cases the elongation required is specified to vary with the strength. Thus an iron is accepted with 46,000 pounds provided the elongation is 30 per cent, and with 51,000 provided the elongation is 27 per cent. The reduction of area of the fracture is occasionally specified, and where dependence is placed on the specification, this requirement is more important than any other in determining the extent to which the iron has been worked and its relative quality. A practical test is frequently specified to ensure that the iron can be rivetted cold without splitting and bending tests are used in which the iron is specified to bend over 180° without fracturing, either hot or cold, the additional requirement being occasionally inserted that it shall be tested in two directions at right angles to each other. A test is also in common use in which the threaded bar is bent for 180° over a bar having a diameter equal to its own. These tests are all directed to ascertain the required physical qualities and requirements have during the past few years been specified which are intended to ensure the suitability of the structure of the material accepted by them for staybolt purposes. A threaded bar is held firmly at one end and vibrated at the other end in a straight line or in a circle. Under these conditions the iron must stand a certain number of vibrations without fracturing. The three leading specifications in use are as follows :

a) The free end of the bolt, which is 6 inches in length, is moved a circle of $^1/_{16}$ inch radius, at a speed of 100 revolutions per minute, and at the same time subjected to tensile strain of 2,400 pounds per square inch. To be accepted the iron must stand the following number of revolutions; $^7/_8$ inch bar 3,000 revolutions, 1 inch bar 2,200 revolutions and 1 $^1/_{16}$ inch bar 1,500 revolutions;

b) The free end of the bar, which is five inches long, is vibrated in a straight line for $^1/_{16}$ inch on each side of the axis of the bar, so that its free end is deflected over a total space of $^1/_8$ inch. The bar is at the same time subjected to a tensile strain of 2,800 pounds per square inch. To be accepted the bar must stand not less than 2,400 double vibrations before breakage.

c) The free end of bar, which five inches in length, is vibrated along a straight line alternately $^1/_8$ inch on each side of axis of bar, so that the end of the bar moves over a space of $^1/_4$ inch. To be accepted the iron must stand not less than 2,000 double vibrations before breakage.

It cannot be said that the various tests referred to above have entirely solved the

question of the best quality of iron for staybolts. A number of administrations still consider that the service test is the most reliable for determining whether a brand of iron of good quality is satisfactory for service, and experience has shown that the physical qualities may vary within wide limits, and yet satisfactory results be obtained. There is no doubt, however, that a high grade of iron is required in order to stand the continued bending which occurs.

While these specifications apply to the material for the staybolts below the top of the firebox, many administrations use the same quality of material for the radial or crown stays, while the others accept iron for this service having a tensile strength of 48,000 to 52,000 pounds and an elongation of from twenty six to twenty eight per cent in 8 inches. The latter practice is satisfactory on account of the greater length of stays above the top of the firebox, for which wrought iron of a reasonably high quality will meet requirements.

Life of fire-boxes. — The life obtained from steel fire-boxes varies considerably with the quality of the water used and with the type of fire-box. No reliable information is obtainable with reference to the influence of the quality of steel on the life of the fire-box with the exception that one administration reports steel having from 0·10 to 0·18 per cent carbon has been found to give better results than steel having from 0·18 to 0·25 per cent while several report that a special brand of acid steel having exceptionally low phosphorous and sulphur has been found preferable. Some administrations with locomotives of an older type in which the fire-box is deep and placed between the frames and where water is of good quality report the life of fire-boxes as high as twenty years and over, but the general experience with modern engines using 180 to 200 pounds boiler pressure is that the life varies from two to four years in bad water districts, up to ten years and over where water is good. The exact life of fire-boxes is difficult to determine from the fact that the various sheets composing it do not last the same length of time. Where the nature of the scale is such that the sheets become easily overheated and the service is severe, side sheets in engines of the wide fire-box type are occasionally replaced in from one to one and a half years, while crown sheets which do not deteriorate so quickly give considerably longer service. Thus one administration reports that side sheets are being renewed in from one to three years while crown and flue sheets average five years life.

It is difficult to present any correct figures on account of the great variation in the conditions The figures given above are fairly representative of the replies received from a number of administrations. The Buenos Ayres & Rosario Railway which use both copper and steel fixe-boxes state that with copper the life of the fire-box has been from ten to twelve years and steel about four years. This would indicate a considerably longer life for copper fire-boxes than for one made of steel, but the copper fire-box has been found impraticable in American service on account of the rapid erosion caused by the sparks, due to the high rates of combustion at

which engines are frequently worked. It should be borne in mind in connection with the life of fire-boxes, that in American practice the miles run per locomotive, per annum are exceedingly high 30,000 to 35,000 miles frequently being obtained while individual engines in passenger service have been run from 6,000 to 7,500 miles per month. Measuring the life of fire-boxes therefore in terms of years does not represent entirely the service obtained, unless the miles run per month or per annum are taken into account and when this is done the service obtained from steel fire-boxes becomes satisfactory. The reason for the rapid deterioration of the side sheets in wide fire-box engines in service where the water is of a bad quality is not entirely clear. It has, however, recently been ascribed to the inclination of the fire-box sheets towards each other at the top so that the bubbles of steam formed next the sheet are not wiped off by the ascending streams of steam bubbles from other portions of the sheet, as is the case with fire-boxes of a narrow type placed between or on top of the frames. Some boilers have recently been constructed in which the width of the fire-box is reduced in order to allow of the inclination of the fire-box sheet being outwards towards the top so as to obtain this action. Whether from this cause or not there is little doubt that overheating of side sheets occur and that the reason is on account of insufficient circulation. Some recent experiments have indicated an improvement may be obtained by arranging for a greater depth of water in the sides of the fire-box below the surface of the grates and this would also confirm the theory that defective circulation is a reason for the short life frequently obtained from side sheets on boilers of the wide fire-box type.

Life of tubes.—The life of tubes varies largely with the quality of the water. It is common practice to safe-end or weld additional portions on to the body of the tube from four to ten times where the water is such that no pitting of the body of the tube occurs. The length of time required before the tube is removed on account of the end being so damaged by rolling and beading that it cannot be maintained in a sufficiently tight condition for proper service, varies, according to the water conditions, and type of engine, from five to six months up to three years and over. On one railway tubes are removed, for safe-ending after forty to sixty thousand miles in freight service and 75,000 to 110,000 miles in passenger service. On another they are removed in bad water districts after five to six months and in relatively good water districts after ten to twelve months. The shortest life of the body of the tube reported is from two to three years while some administrations report tubes lasting as long as fifteen years and over. Where no pitting occurs and the water is of an average quality, the life of the body of the tube will average from eight to twelve years before it is scrapped on account of insufficient strength. The Buenos Ayres & Rosario Railway which use both brass and iron tubes report brass tubes as lasting from ten to twelve years while iron tubes are scrapped after four years on account of pitting. This evidently is caused by the quality of the

water and there would not appear to be a very great difference between the life of the brass and iron tubes where the water is not of such a quality that the body of the tube is attacked.

B. — Boilers with water tubes. — Steam superheaters and valve gear for superheated steam. — Feed water heaters.

Water tubes. — None of the replies received indicate that any water tube boilers are in use.

Steam superheaters. — The replies received from the various administrations with respect to the use of superheated steam are extremely meagre and with one exception those roads which have equipped engines with superheating appliances have done so as an experiment only. The Canadian Pacific Railway has, however, adopted it extensively and has at the present time about four hundred and seventy five (475) engines using superheated steam. In 1901 this road applied a " Schmidt " smoke-box superheater to an 18 inch by 24 inch cylinder, 4-6-0, freight engine with 62 inch. wheels, and the results obtained from this experiment being satisfactory, two years later, two 4-6-0 compound freight engines were equipped with superheaters of the " Schmidt " smoke tube type. These engines also showed a substantial economy over similar engines without superheaters, and in 1904 forty one (41) simple, 2-8-0, freight engines were constructed, twenty of which were equipped with " Schmidt " smoke tube type of superheater and twenty one with the " Cole " superheater of the " Field " tube type. The " Cole " superheaters did not prove satisfactory and were removed after about a year's service, but the engines with the " Schmidt " smoke tube superheaters were entirely successful and during their first six months service showed a saving of 18 per cent, in fuel compared to compound, 2-8-0, engines of a similar though slightly smaller type which had been constructed two years previously.

This economy was not entirely due to the use of superheated steam, as the compounds were not in as good condition as the newer engines, but it was regarded as showing that the superheated steam engines were more efficient, and that they could with economy be used in place of compound engines which had proved expensive to maintain.

Following these engines the Canadian Pacific Railway constructed fifty 4-6-0 simple freight engines, ten of which were equipped with the " Schmidt " smoke tube, thirty with the " Cole " return bend smoke tube and ten with " Vaughan-Horsey " smoke tube superheater, which is a design developed on that road. Since, that time, with the exception of twenty five engines equipped with the " Cole "

return bend superheater, all new freight and passenger engines constructed have been equipped with the " Vaughan-Horsey " smoke tube superheater and fifty five engines with the " Cole " return bend design have also been converted to that type. In addition this superheater has been applied to twelve, 4-6-0, simple passenger engines and one, 4-4-2, passenger engine. A list of the engines now equipped is as follows.

Number.	Type.	Cylinders.	Driving wheels.	Boiler pressure.	Weight on drivers.	Total weight.	Type of superheater.
1	4-6-0	18 × 24	62 inches.	180	95,425	119,225	Schmidt smoke box.
1	4-6-0	22 and 35 × 26	63 —	200	128,000	169,000	— — tube.
1	4-6-0	22 and 35 × 30	63 —	200	147,075	192,150	— — —
10	4-6-0	21 × 28	63 —	200	141,000	190,000	— — —
105	4-6-0	21 × 28	63 —	200	141,000	190,000	Vaughan-Horsey.
115.	4-6-0	22-1/2 × 28	63 —	180	141,000	190,000	— —
12	4-6-0	20 × 26	69 —	200	129,450	166,000	— —
1	4-4-2	20 × 26	84 —	200	97,310	170,250	— —
17	4-6-2	21 × 28	75 —	200	139,000	212,000	— —
83	4-6-2	21 × 28	69 —	200	139,300	214,300	— —
20	2-8-0	21 × 28	57 —	200	168,150	192,350	Schmidt smoke tube.
110	2-8-0	22-1/2 × 28	57 —	180	171,900	195,500	Vaughan-Horsey.

The results obtained have been on the whole exceedingly satisfactory. Figures derived from extensive service on all sections of the road, and based on the total quantity of fuel delivered to the engines have shown an economy in fuel of from 10 to 15 per cent in passenger service.

A noticeable difference between simple engines using superheated steam and two cylinder compound engines using saturated steam is also found in the greater flexibility of the simple engine. Under conditions favorable to the compound engine when it is working on a level road or otherwise uniformly worked at slow or moderate speeds, its efficiency is equal or but slightly below that of the superheater engine, but when on a undulating road or when worked at high speeds the economy of the superheater engine is decidedly superior. No opportunity exists on the Canadian Pacific Railway of comparing simple superheater steam engines with four cylinder compound engines in passenger service, but as compared with simple saturated steam engines, in addition to the economy above mentioned, superheated steam engines of identical design develop at least 10 per cent greater sustained power and also run more freely and faster.

*

It should be mentioned that the figures for economy given above are not for the purpose of showing the best results that have been obtained, but rather a conservative estimate of the average saving that has been effected on a large number of engines working under average conditions, and on which no effort was made to obtain good results from engines using superheated steam rather than from other engines and it is fairly representative of the saving that may be expected.

Experiments to determine the amount of superheat obtained show that with the " Schmidt " superheater on a, 2-8-0, freight engine, having a boiler pressure of 200 pounds per square inch corresponding to a temperature of 388° Fahr., the temperature of the steam in the steam chest averaged from 440° Fahr., to 480° Fahr., according to the way in which the engine was worked, the higher temperature occurring when the engine was worked to a greater capacity.

Tests of the " Vaughan-Horsey " superheater in passenger service with the same boiler pressure showed an average temperature in the steam chest of 540° Fahr., averaging from 520° Fahr., to 560° Fahr., according to the way in which the engine was worked and in some instances a temperature of 580° Fahr., was slightly exceeded.

The " Vaughan-Horsey " superheater in freight service showed a temperature in the steam chest of 500° Fahr., averaging from 480° Fahr., to 520° Fahr., according to the working of the engine. Experiments that have been made appeared to show that with this style of superheater a rather higher degree of superheat is obtained with a corresponding number of superheater tubes than with the " Schmidt " superheater, probably due to the form and arrangement of the headers, but it has been found that no increase in the temperature of the superheated steam is obtained when four superheater pipes are included in one element, or in other words, when the steam is caused to travel through four superheater pipes in its passage from the superheated steam header to the saturated steam header. With the " Schmidt " superheater, this increase takes place and the superheat obtained is practically the same as with the " Vaughan-Horsey " arrangement.

Fourteen administrations in the United States have experimented with engines using superheated steam, the number of engines reported being seventy in all. The majority of these are equipped with the « Vauclain » superheater which is somewhat similar to the « Schmidt » smokebox superheater with the exception that the large flue used in the latter design by which a high temperature is obtained in the superheater is not used. Information is not available as to the actual result obtained by this superheater but the tests reported would indicate that the temperature of the steam in the steam chest is from 25° to 40° Fahr. ; above that corresponding to the pressure of the steam in the boiler. This test also showed a saving in coal consumption of 11 per cent as compared to a corresponding simple engine. Results reported by other administrations using superheaters of the " Schmidt " or " Cole " return bend type are universally favorable to a more extensive use of this device.

Accurate figures are not obtainable but the saving reported in fuel varies from ten per cent to twenty eight per cent as compared to corresponding simple engines. Neglecting the extreme figures given it would appear that the experience on these roads very well confirms the average results reported for the Canadian Pacific Railway.

An extensive series of tests was conducted at Purdue University by Professor W. F. M. Goss for the Carnegie Institute, Washington, D. C., the results of which were presented by Professor Goss in a paper read before the American Railway Master Mechanics Association at its Convention in 1909 (1). The economy in fuel obtained with a temperature of the superheated steam of about 150° Fahr., above that corresponding to saturated steam at the boiler pressure averaged from ten to fifteen per cent, and deductions were drawn to show that with a boiler pressure of 180 pounds per square inch and steam superheated 200° a saving of 19 per cent should be anticipated. This report was criticised at the Convention as possibly under-estimating the saving that could be obtained. In the first place, on account of the boiler of the engine on the testing plant being comparatively small, the application of a smoke tube type of superheater reduced the amount of evaporating surface to a greater extent than is the case when the same apparatus is applied to a larger boiler. In the second place the comparisons at high pressures were made against the saturated steam engine under testing plant conditions in which steam leaks of every description were as far as possible eliminated thus obtaining better results on the high pressure saturated steam engine than would be possible in actual service. The results obtained on the testing plant, were also compared upon the basis of equal rates of evaporation, while under service conditions, in which an engine using superheated steam is worked in comparison with one using saturated the comparisons are actually referred to equal amounts of power developed. This leads to two possible explanations of the greater economy reported in road service than that obtained in a testing plant. The first is that whereas with the smoke tube type of superheater, in which steam of a greater thermal value is delivered to the engine, and a portion of the products of combustion are ejected at the front end of the boiler at a higher temperature than would be the case in an engine using saturated steam, it would be expected that the economy in water consumption would be greater than that in fuel, it is universally reported that actual experience shows the reverse. This would at first appear contradictory, but consideration will show that as the efficiency of the boiler varies with the rate at which it is worked, any saving in the steam consumption will lead not only to a corresponding saving in fuel consumption, but to a greater saving, in proportion to the decrease in the rate of combustion. Thus, assuming a decrease in the steam consumption when an engine is exerting a given amount of power of twenty per cent, and neglecting

(1) This paper is reprinted in the *Bulletin of the Railway Congress*, No. 2, February 1910, page 654.

the difference in the evaporative efficiency of a boiler delivering superheated steam from one delivering saturated steam, a decrease of 20 per cent in the steam evaporated will lead to a decrease in the coal consumed of from twenty five to thirty per cent, on account ot the lower rate of combustion and the more efficient transfer of the heat from the products of combustion to the water in the boiler. This increase in efficiency is evidently more than sufficient to balance the decreased efficiency of the superheated steam boiler as compared to the ordinary boiler, and the anomaly of the greater saving in coal than in water is thus explained. In the second place any cause leading to a reduction in the demand on the fireman enables him to fire more carefully and by doing so obtain better results than when his energies are over-taxed. On a test plant this condition does not exist as the firing is uniformly performed with the greatest care in order to obtain comparative results, but in road service the reduced consumption of steam of a superheater engine may lead to a greater economy than anticipated owing to more economical firing.

The general experience in Canada and the United States therefore with regard to the use of superheated steam may be summarised by the statement that a substantial economy in coal has been effected, that on account of conditions this economy is not as great in freight service as in passenger service, and in the latter a considerable benefit is obtained from the increase in the capacity of the engine. As against this advantage there are two possible disadvantages, *viz.*, an increase either in the cost of maintenance or in the number of failures or breakdowns on engines when hauling trains.

With reference to the cost of maintenance no figures are available except on the Canadian Pacific Railway and on this road comparisons are made difficult, by the fact that for some years previous to the introduction of the simple engine using superheated steam, the engines constructed had been of the two cylinder compound type which has proved exceedingly expensive to maintain. It is therefore impossible to present accurate figures comparing an ordinary simple engine with those of a corresponding type using superheated steam, but it may be stated, that a careful study of the cost of repairs on this road shows that the cost of maintenance of superheaters is little if any greater than that which would be expected from an ordinary engine. The addition of any device of this nature must necessarily entail some increased cost of maintenance. This additional cost would be offset to a certain extent, or possibly entirely by the elimination of the damage occasionally caused by the presence of water in the cylinders, and the engines have on the whole proven exceedingly economical in maintenance, and it is not felt that in this respect the addition of a superheater is likely to prove at all serious.

The increase in engine failures on account of the application of a superheater was at first very small. As the number of engines in service increased, it became more serious, which lead to steps being taken to remedy such trouble as developed, and during the last year or more difficulties have been almost entirely overcome.

Most of the troubles occurred through leaking at the connections of the superheater pipes to the headers. This developed on both the " Schmidt " and " Vaughan-Horsey " types but especially with the latter. With the " Schmidt " superheater, leaks would occasionally develop between the flanges into which the superheater pipes are expanded and the face of the header; if neglected, and experience showed that these leaks might easily be neglected as they did not appear to at first affect the steaming qualities of the engine, the face of the header became eroded and the work of remaking the joints would be rendered difficult and expensive. This difficulty was entirely overcome by fastening each flange to the header by four studs in place of the clips used in the original design, and with this alteration the trouble from leakage at this point has practically disappeared.

In the " Vaughan-Horsey " superheater, considerable trouble has occurred through the nuts getting slack, which connect the superheater pipes to the header fittings. This was found to be largely due to their not being of a sufficiently good fit, and has been overcome by better workmanship, a heavier design of nut, and the application of a simple type of lock nut which prevents any movement taking place.

Both designs of superheaters are liable to one other and very annoying trouble, *viz.*, the occasional burning out of the return bends which connect the superheater pipes to the fire-box end. This is caused entirely by not properly maintaining the dampers which prevent the heated gases passing through the superheater tubes when steam is not being used by the engine and the superheater pipes are empty. The difficulty does not develop immediately, and if the dampers are not kept in proper operating condition some time may elapse before any effect is shown. When the failure of a return bend occurs the superheater pipes or return bends are found to have been badly damaged by exposure to high temperatures for a considerable length of time. The remedy for this class of failure is of course the proper maintenance of the dampers, and this in turn is largely affected by their proper design, so that it is important that they be arranged so as to work properly, and the possibility of their binding or becoming stuck in an open or shut position must as far as possible be avoided.

Reference has been made to various designs of superheaters. The " Schmidt " smoke box and smoke tube superheaters used in the United States and Canada are of practically the same design as those which have been extensively used in Europe and do not therefore require illustration. The " Cole " superheaters are not now used, but have been superceded by a design of smoke tube superheater which has recently been developed by the American Locomotive Compagny and is illustrated in figures 40 and 41.

The superheated and saturated steam headers are arranged on either side of the smoke-box and the superheater pipes are bent to these headers, the connections being made by ground rings having a flat face on one side and a spherical face on the other, similar to those used for making steam pipe joints in American practice.

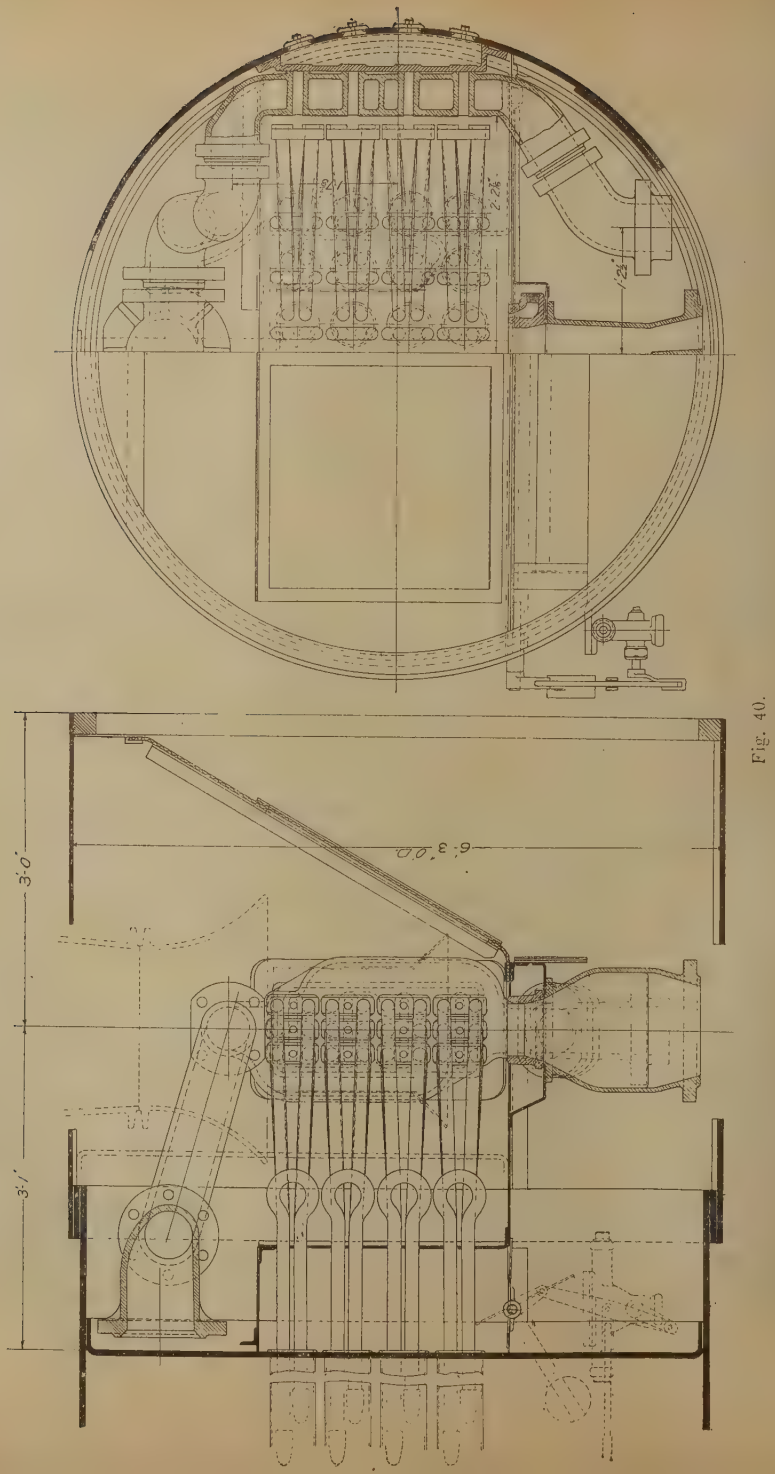


Fig. 40.

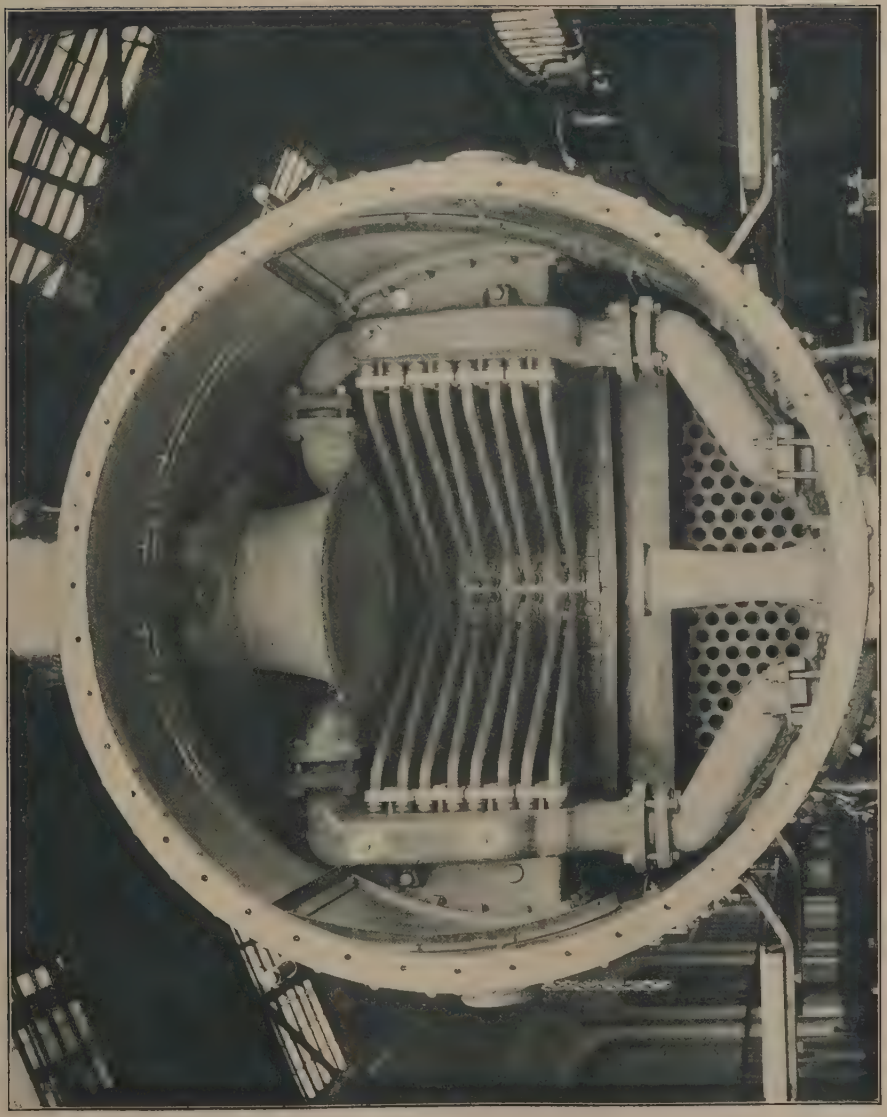


Fig. 41.

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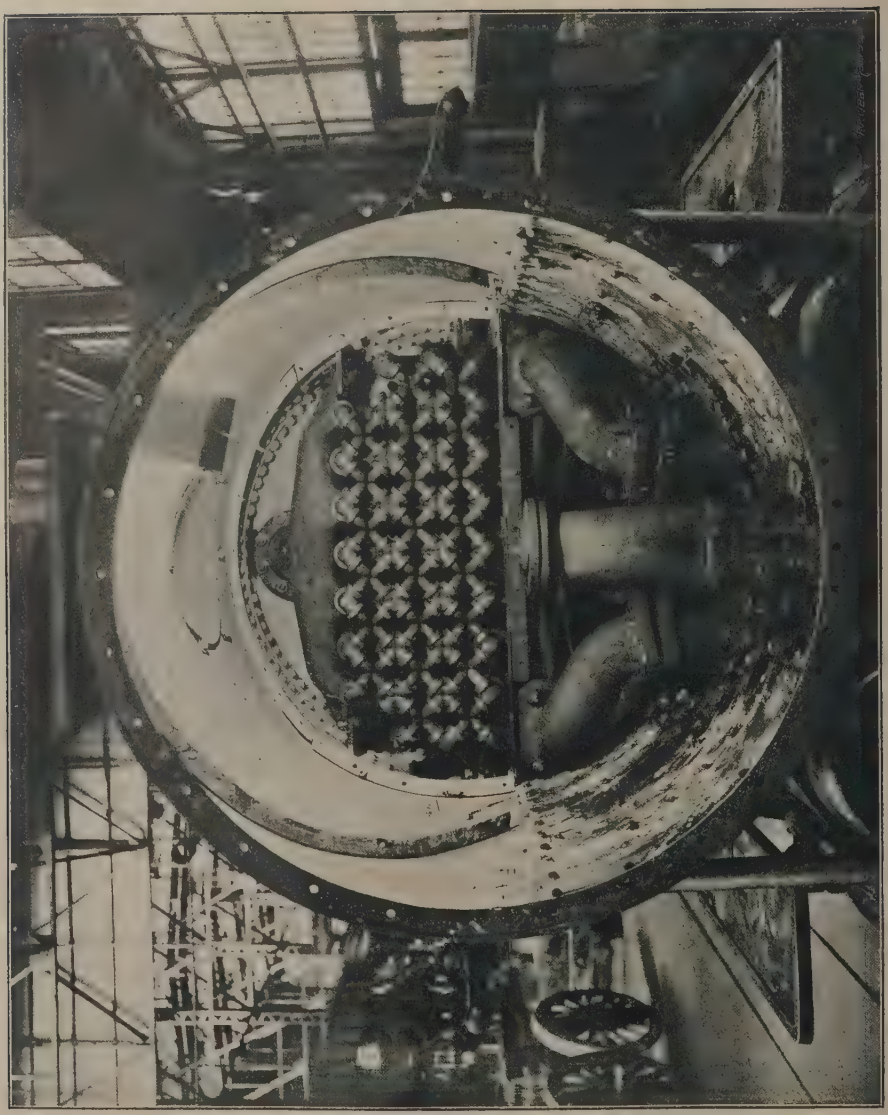

Fig. 42.

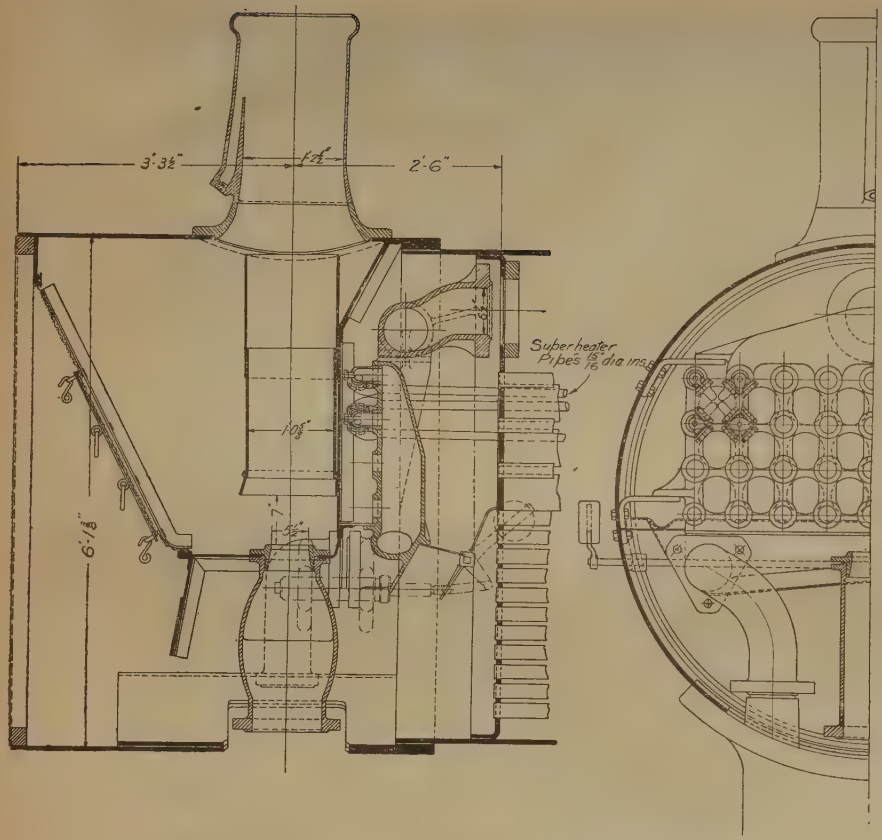

Fig. 43.

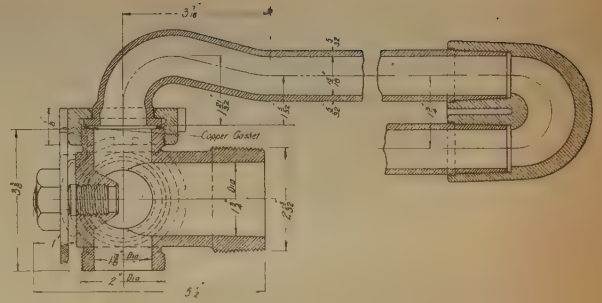

Fig. 44.

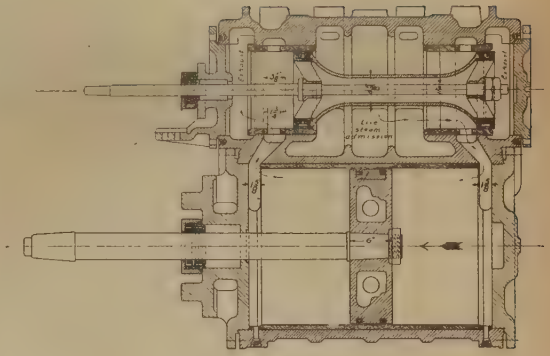

Fig. 45.

The superheater pipes pass through a diaphragm plate in the front of the tube sheet, and small malleable iron fittings are used to fill up the spaces around the tubes and support the pipes where they pass through the diaphragm plate. The arrangement of this superheater is clearly shown in the drawing and does not call for any explanation. It has been applied, or is being applied, to twenty five engines on ten different railways and should apparently prove entirely successful as it combines the requirement of flexibility in the superheater pipes to allow of expansion, together with ease of accessibility to the joints and superheater pipes.

The " Vaughan-Horsey " superheater which has been referred to is illustrated in figures 42 and 43.

In this superheater the headers are placed directly in front of the tube sheet, and each header is provided with a number of sub-headers.

The sub-headers attached to the saturated and superheated steam headers respectively being disposed alternately in vertical rows. To each sub-header superheater pipes are connected, passing through the superheater tubes on each side of the sub-header, while the connections between the superheater pipes and the sub-headers are made by union nuts and fittings, shown in detail in figure 44. It will be seen that these two designs of superheaters, the American Locomotive Company's and the " Vaughan-Horsey ", are in many respects similar to the " Schmidt " smoke tube superheater, but vary from it in the design and arrangement of the headers and superheating pipe connections.

In American pratice, no advantage is gained by exposing the ends of the large superheater tubes at the smoke-box end, for the purpose of cleaning, as tubes are invariably cleaned from the fire-box end, and the chief objects desired have been found to be ease of accessibility to the joints between the superheater pipes and the headers for the purpose of inspection and tightening of joints, and the possibility of removing one element or pair of superheater pipes without disturbing any others.

With the later design of " Schmidt " smoke tube superheater, this can easily be effected, but with the earlier designs the removal of one element of superheater pipes from one of the top rows of superheater tubes, necessitated the removal of two or three sets of joints, and possibly loosening and disturbing others. With the short time available for repairs on engines in the United States, on account of the large amount of mileage that they are expected to make, any device causing delays at terminals for repairs is strongly objected to. With the " Vaughan-Horsey " type of superheater, any pair of superheater pipes may be easily removed without disturbing others, and this advantage is also found to an almost equal extent in the superheater of the American Locomotive Company. In both cases also, if superheater pipes are defective they can be removed and blank joints applied to the headers in their place, and the pipes replaced at the first convenient opportunity.

With the exception of the original engine referred to as having been equipped with the " Schmidt " smoke-box superheater all engines equipped with superheaters in

the United States and Canada have used the ordinary type of piston packing, piston rod packing, piston valve, and piston valve packing rings, commonly used in the United States for saturated steam. The practice varies slightly on different roads but figure 45 shows the design of these various details used on the Canadian Pacific which may be accepted as fairly representative. The only detail in which any difficulty is experienced is with the packing rings in the piston. These are found to wear considerably more quickly in engines using superheated steam than in those using ordinary saturated steam, the average life in the former case being about two months against eight to ten months in the latter. It is not due to any absence of lubrication as the cylinders and pistons when examined appear to be thoroughly well lubricated and it is affected considerably by the quality of the material used in the rings. If the latter are of hard close grained cast iron considerably better service is obtained, but the wear becomes exceedingly rapid if the quality of the iron is soft and this is noticeable to a greater extent than in engines using saturated steam.

It has been found that the best lubrication is obtained by the use of an ordinary type of sight feed lubricator in which the oil is carried into the cylinder and steam chest by a small jet of steam. A number of lubricators of the forced feed or pump type have been used but have not on the whole given good satisfaction. The rate at which they feed the oil does not correspond to the requirements as it is in proportion to the number of revolutions of the engine, in place of a uniform rate per minute, whereas the greatest amount of lubrication is required per minute when the engine is working slowly up heavy grades at a small number of revolutions. The sight feed lubricator is quickly and easily adjusted to give an increased amount of oil per minute, but under theses conditions, pump feed lubricators work exceedingly slowly and require constant adjustment to deliver proper amount of oil. On account also of the loss of pressure in the steam passing through the superheater, there is always a sufficient difference in the pressure between the boiler and the steam chest to ensure a regular amount of oil being fed to the cylinders with the sight feed lubricator, so that is has given more satisfactory results on superheater engines than on those using saturated steam, in which the steam chest pressures is frequently very closely equal to that of the boiler.

The packing for piston rods and valve stems shown in these illustrations is to a certain extent special in form. The type of packing previously used, in which a plastic ring of metal was pressed into a cone shaped collar fitting over the rod, proved at first unsatisfactory when using superheated steam on account of the melting point of the plastic metal used not being sufficiently high. Subsequent experiments have however, shown that when the latter contains approximately 49 per cent, of lead, 50 per cent copper, and 1 per cent tin this form of packing gives satisfactory results. In general no special difficulty has been experienced with forms of packing successful on saturated steam engines, except the occasional necessity of using a metal having a higher melting point.

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Feed water heaters. — Feed water heaters have only been used to a slight extent in an experimental way. No information has been furnished by any of the administrations replying with reference to the results obtained, and your Reporter is therefore unable to present any information with reference to them. The saving in fuel consumption is as is well known 10 per cent for every 10° Fahr. increase in temperature of the water passing through the heater, and some economy has been obtained on certain roads by passing the exhaust from the air pump into the tender. This practice has proved satisfactory, with the exception that the enginemen are obliged to watch the temperature of the water in the tender closely in order to prevent its becoming too hot to be lifted by the injectors.

Roads using this practice frequently use the non-lifting type of injector which will work when the water is at a temperature of 130° Fahr.

APPENDIX I.

The information given in this report has largely been obtained from replies received to a letter of enquiry from the following administrations :

ROAD.	Number of locomotives owned.
Atlanta & West Point Railway	33
Baltimore & Ohio Railroad	1,915
Bessemer & Lake Erie	113
Boston & Maine	1,095
Central of New Jersey	479
Central Vermont	102
Chicago & Western Indiana	81
Chicago, Burlington & Quincy Rallway	1,598
Chicago, Rock Island & Pacific	1,390
Cincinnati, Hamilton & Dayton	249
Cumberland Valley Railway	65
Delaware & Hudson	471
Delaware, Lackawanna & Western	770
El Paso & South Western Railway	159
Grand Rapids & Indiana	92
Hocking Valley	158
Illinois Central	1,267
Missouri, Kansas & Texas	537
Mobile & Ohio	265
Mobile, Jackson & Kansas City	45
New York Central & Hudson River	1,894
Lake Shore & Michigan Southern	921
Michigan Central	548
Cleveland, Chicago, Cincinnati & St. Louis	736
Oregon Short Line	251
Pennsylvania Lines West	1,685
Pennsylvania Railroad	4,094
Queen & Crescent Route	210
Rutland Railroad	82
Seaboard Air Line	431
St. Louis & San Francisco	889
St. Louis & South Western	204
Southern Railway	1,534
Toledo, Peoria & Western	28
Union Pacific & Southern Pacific	1,959
Vandalia Railroad	221
Grand Trunk	1,192

The number of engines refer to the number of engines owned or which are covered by the replies received.

[621 .133.3 & 621 .134.3]

REPORT N° 4

(Austria-Hungary, Rumania, Bulgaria, Servia and Turkey)

By Franz GERSTNER,

STATE COUNCILLOR,
INSPECTOR-GENERAL AND SUPERINTENDENT OF THE ROLLING STOCK AND LOCOMOTIVE DEPARTMENT
OF THE AUSTRO-HUNGARIAN STATE RAILWAY.

Subject VI, littera *B*, includes several heads :

I. — Locomotive boilers with water tubes.
II. — Steam superheaters and valve gear for superheated steam.
III. — Feed-water heaters.

I. — Water-tube boilers.

The only kind of locomotive water-tube boiler used in the countries this report deals with, is the Brotan boiler. This boiler, which was invented by Chief Inspector Brotan, Works Manager of the Austrian State Railway, is a combination of a smoke-tube and a water-tube boiler, for the barrel together with the smoke-tubes and the two tube-plates is of the same design as in the ordinary locomotives used up till now, while the fire-box can be considered a water-tube boiler. A further peculiarity of the Brotan boiler is that a steam chamber and upper drum are placed above the barrel and the fire-box. The fire-box and the fire-box shells of the ordinary boiler are replaced by vertical water-tubes made of iron and placed next each other, which extend from one common foundation ring to the upper boiler. These tubes, which are close together, form the walls of the fire-box; two other tubes (one only on one locomotive) enable the water to flow from the barrel through the foundation ring and the fire-box tubes into the upper drum. This design of combined smoke-tube and water-tube boiler has a very large water space and a sufficiently-large steam space; the water circulates well and consequently evaporates quickly; the formation of scale in the tubes is effectively prevented by the active movement of the water. This system of construction is strong and there are no particular difficulties in the maintenance; these are certainly less than with the ordinary

*

locomotive boilers with copper fire-box. The boilers give good results as regards steam production and the keeping up of pressure, and these are special advantages in the case of long runs.

The motive which led the inventor to adopt this arrangement, was above all the desire to overcome those difficulties which have arisen on the one hand from the large dimensions of the boilers, particularly of the copper fire-boxes, and on the other from the high pressures. It is well known that copper does not stand high temperatures, and that its strength is very quickly reduced at very high temperatures; the large size of the fire-box walls leads to objectionable deformation of the sides, the tube-plate and the back plate; the tube-plate " grows " and this deforms the tube holes, which lose their round shape and become oval, and the joints begin to leak. The maintenance of the sides, the roof bolts and stays and their heads, is also of very great importance. Everybody who has had anything to do with boiler maintenance knows that in large boilers with high pressures, the roof bolts and stays do not stand their work well; fractures often occur and the sides become very irregular in surface, particularly if the feed-water is of inferior quality. In order to overcome these difficulties, this new design was adopted, in which there is no copper, no roof bolts and no stays, and which makes it possible to use coal containing sulphur, which must not be used in copper fire-boxes; the Brotan fire-box built of iron Mannesmann tubes stands this fuel well and does not get corroded to the same extent or as quickly as copper.

Figure 1 shows such a boiler as used on a locomotive of the Hungarian State Railway; its total capacity is 7·5 cubic metres (1,650 English gallons). The Brotan boiler of locomotive series 174 of the Austrian State Railway has a total capacity of 7·1 cubic metres (1,563 English gallons), a water surface of 5·3 square metres (57·05 square feet), a direct heating surface of 11·6 square metres (124·87 square feet), an indirect heating surface of 169·0 square metres (1,819·17 square feet); and accordingly a total heating surface of 180·6 square metres (1,944·03 square feet).

In the countries this report deals with, Brotan boilers have been used in the following cases :

RAILWAY.	Design of locomotive.	Brotan locomotive boilers in use since the year									In use.	Being built.
		1901.	1902.	1903.	1904.	1905.	1906.	1907.	1908.	1909.	June 1909.	
Austrian State Railway	0-C-0	1	4	...	...	...	3	...	...	...	8	...
	2-B-0	...	...	...	1	5	1	...	...	...	7	...
	0 D-0	...	...	...	...	...	1	1	11	...	13	...
Bohemian Northern Railway	0-C-0	...	...	...	...	...	...	...	1	...	1	...
Hungarian State Railway	2-B-0	...	...	...	...	...	1	...	...	...	1	...
	0 B-0	...	...	...	...	...	...	...	2	...	2	...
	0-C-0	...	...	...	...	...	...	...	...	...	...	2
	0-C-0	...	...	...	...	...	...	...	...	...	...	2
Kaschau-Oderberg Railway	0-C-0	...	...	...	...	...	...	1	1	...	2	5
Total.		1	4	...	1	5	6	2	15	...	34	9

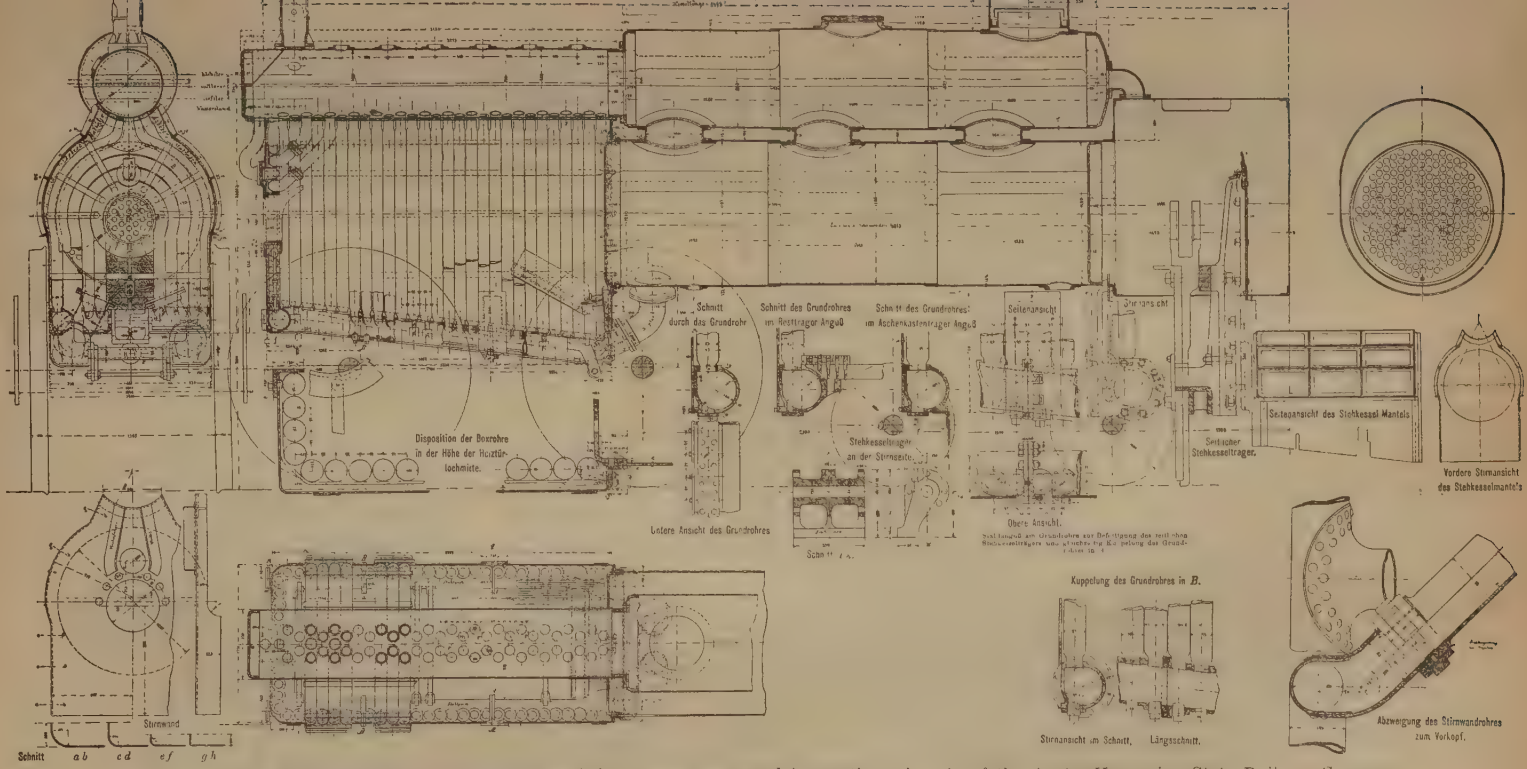


Fig. 1. — Water-tube fire-box boiler (Brotan system) for express compound locomotives class 1*e* of the Austro-Hungarian State Railway Company.

CHIEF DIMENSIONS :

Grate area, 3 square metres (32·29 square feet). Number of smoke tubes, 223. Heating surface of smoke tubes, 146 square metres (1,571·59 square feet); of fire-box, 18·8 square metres (202·37 square feet; total, 164·8 square metres (1,773·96 square feet). Working pressure, 13 atmospheres.

Explanation of German terms : Schnitt = Section. — Stirnwand = Front end. — Disposition der Boxrohre in der Höhe der Heiztürlochmitte = Arrangement of fire-box tubes at height of middle of fire-door hole. — Schnitt durch das Grundrohr = Section through bottom tube. — Untere Ansicht des Grundrohres = Bottom tube. View from below. — Schnitt des Grundrohres im Rostträger Anguss = Section of bottom tube at grate bearers. — Schnitt des Grundrohres im Aschenkastenträger Anguss = Section of bottom tube at ash-pan bearers. — Stehkesselträger an der Stirnseite = Support of vertical boiler front. — Seitenansicht = Side view. — Stirnansicht = Front view. — Stahlguss am Grundrohre zur Befestigung des seitlichen Stehkesselträgers und gleichzeitig Kuppelung des Grundrohres in A = Steel casting at bottom tube for fastening the vertical boiler support and at the same time making its joint at A. — Obere Ansicht = View from above. — Seitlicher Stehkesselträger = Verticaler-boiler support at side. — Seitenansicht des Stehkesselmantels = Side view of vertical-boiler shell. — Vordere Stirnansicht des Stehkesselmantels = Front view of vertical-boiler shell. — Kuppelung des Grundrohres in B = Joint of bottom tube at B. — Stirnansicht im Schnitt, Längsschnitt = Front view, Section. Longitudinal section. — Abzweigung des Stirnwandrohres zum Vorkopf = Branch of front tube to drum.

In other countries, 17 Brotan boilers are at present in use and 16 more are being constructed.

The Brotan boiler is also used in some districts where the feed-water is very hard and impure; its maintenance in these cases presents fewer difficulties than that of the ordinary friction boilers.

The Brotan boiler is at present still to some extent in the experimental stage; it has not yet been in use long enough to allow a full and conclusive opinion to be formed as to its merits. It may however be mentioned as an advantage of this interesting design, that the use of expensive copper and of the stays is avoided by means which are not too complicated, the steam production being increased at the same time. The weight of a Brotan boiler is very nearly the same as that of a boiler of the ordinary shape and of the same power. A disadvantage of the Brotan boiler is that it produces wetter steam than the ordinary boiler, and that consequently, priming occurs when it is worked to its full power and used for a long time. This disadvantage can be overcome effectively by using a separator or drier (of the Clench or Austrian State Railway type) or by using a superheater. The production of steam which is too wet, results from the less favourable ratio between the steam production and the water surface available for the steam to pass through. The inventor has tried to improve matters by eliminating the upper drum and using a barrel of large diameter, giving a large water surface and at the same time a sufficiently-large steam space. This arrangement is already in use on some of the locomotives of the Swiss Federal Railway, of the Swedish State Railway and of two Russian lines.

In the countries with which this report deals, none of the different arrangements of the water tubes in the fire-boxes of locomotives (cross tubes) are in use. Boilers which are wholly water-tube boilers, without barrel or smoke tubes, have just as little found any application.

II. — Steam superheaters and valve gear for superheated steam.

The idea of overcoming the disadvantages of steam which is very wet and profiting by the use of perfectly-dry steam instead of wet steam having the same pressure, was first entertained, in the case of locomotives (as it had previously been in that of stationary engines), about thirty years ago. In France in 1879 and 1880, Auguste Estrade, Louis M. Rist and Baron Seillière designed and constructed superheaters for locomotives; but the use of these systems was very limited and they disappeared very soon. At a rather long interval, the subject was again taken up by a number of people; the numerous forms which have appeared clearly indicate the desire of the inventors to obtain considerable superheat by as simple means as possible and, while saving weight and expense as much as possible, yet at the same time to devise designs which would ensure good and cheap maintenance.

The different systems of locomotive superheaters can be divided into the following three classes :

1° Superheaters placed in the smoke box;

2° Superheaters placed in the barrel, utilizing heat given off by the smoke tubes, to superheat the steam;

3° Superheaters placed in the smoke tubes themselves, which utilize part of the direct heat of the hot gases passing from the fire-box to the smoke-box.

The first class includes the superheater of the Hanover Locomotive Works (Egestorff), of Ranafier, of Hagans with separate oil-firing in the smoke-box, of Löw; also the smoke-box superheater extensively used in Germany and manufactured by W. Schmidt of Wilhelmshöhe (Cassel).

The second class includes the devices of Clench and the Austrian State Railway, of Pielock and of Slucki.

The third class includes the superheaters of Vaughan and Notkin, the American Schenectady superheater (Cole), that of Cockerill (Seraing), and the smoke-tube superheater of W. Schmidt of Wilhelmshöhe (Cassel), the use of which is extending continually and which will be described specially.

Several other designs, owing to their peculiarities, cannot be included in either of the above groups; thus for instance, the first superheater of Schmidt, dating back to 1897, in which a battery of superheater elements is placed in one large central smoke tube, and the Klose design, in which part of the upper sets of the smoke tubes is equipped as a superheater, with a special dome with a superheater battery superposed.

The reporters for the other countries will not neglect to explain in detail the advantages and disadvantages of the systems named above; as regards the countries this report deals with, only a few designs can be discussed, and that only as far as Austria is concerned, where a considerable number of locomotives equipped with superheaters are already in use; in the other contries (Hungaria, Rumania, Bulgaria, Servia, Turkey), superheated steam is not yet used; but a considerable number of locomotives equipped with superheaters have already been ordered.

The superheater systems at present applied in Austria are :

1° The Clench design and Austrian State Railway separator;

2° The Pielock superheater;

3° The W. Schmidt smoke tube superheater.

The Clench design and Austrian State Railway separator is in use as follows :

Austrian State Railway : on 138 locomotives in use and on 105 which are being built;

Austrian Southern Railway : on 6 locomotives in use;

Bukovina Local Railway : on 3 locomotives in use.

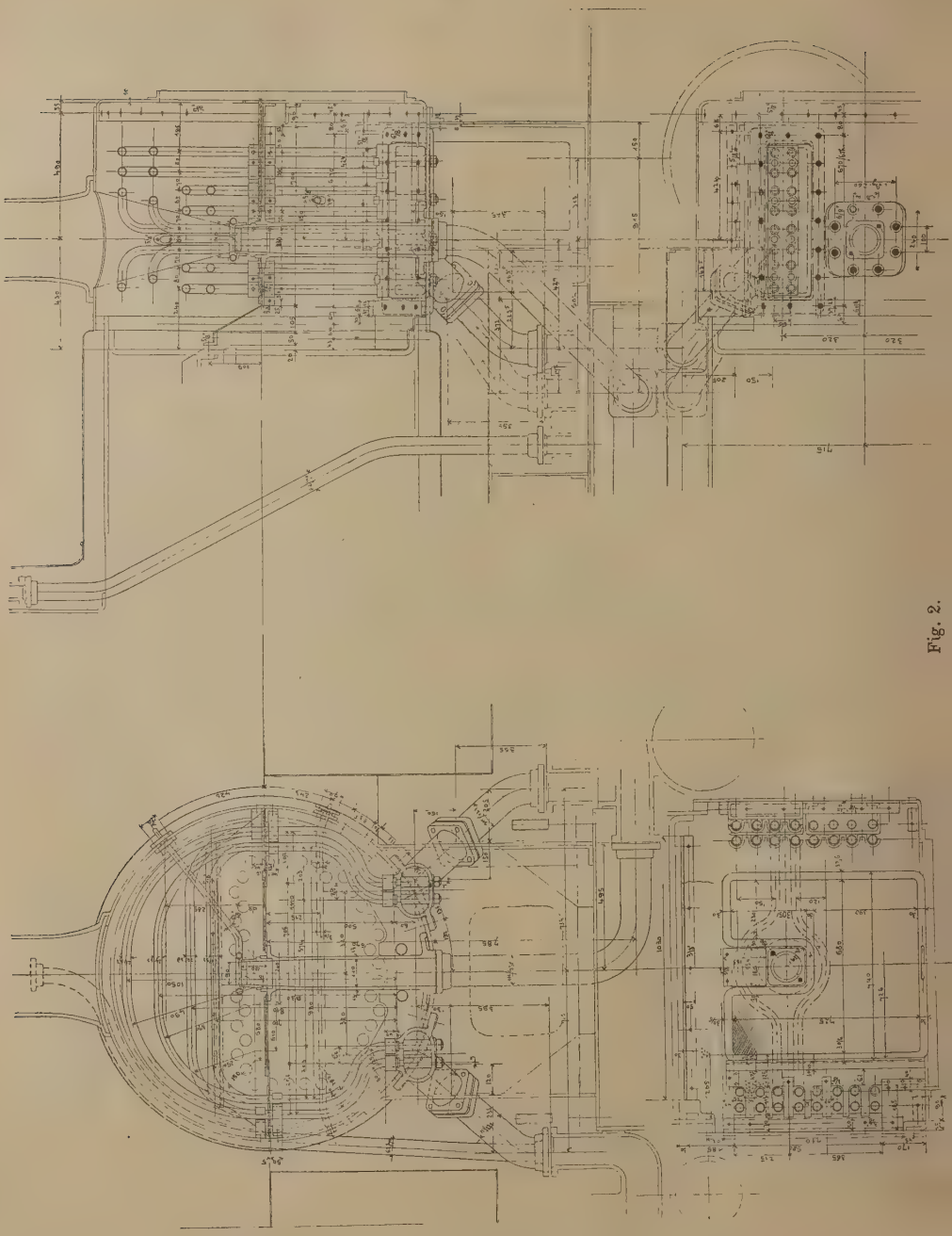


Fig. 2.

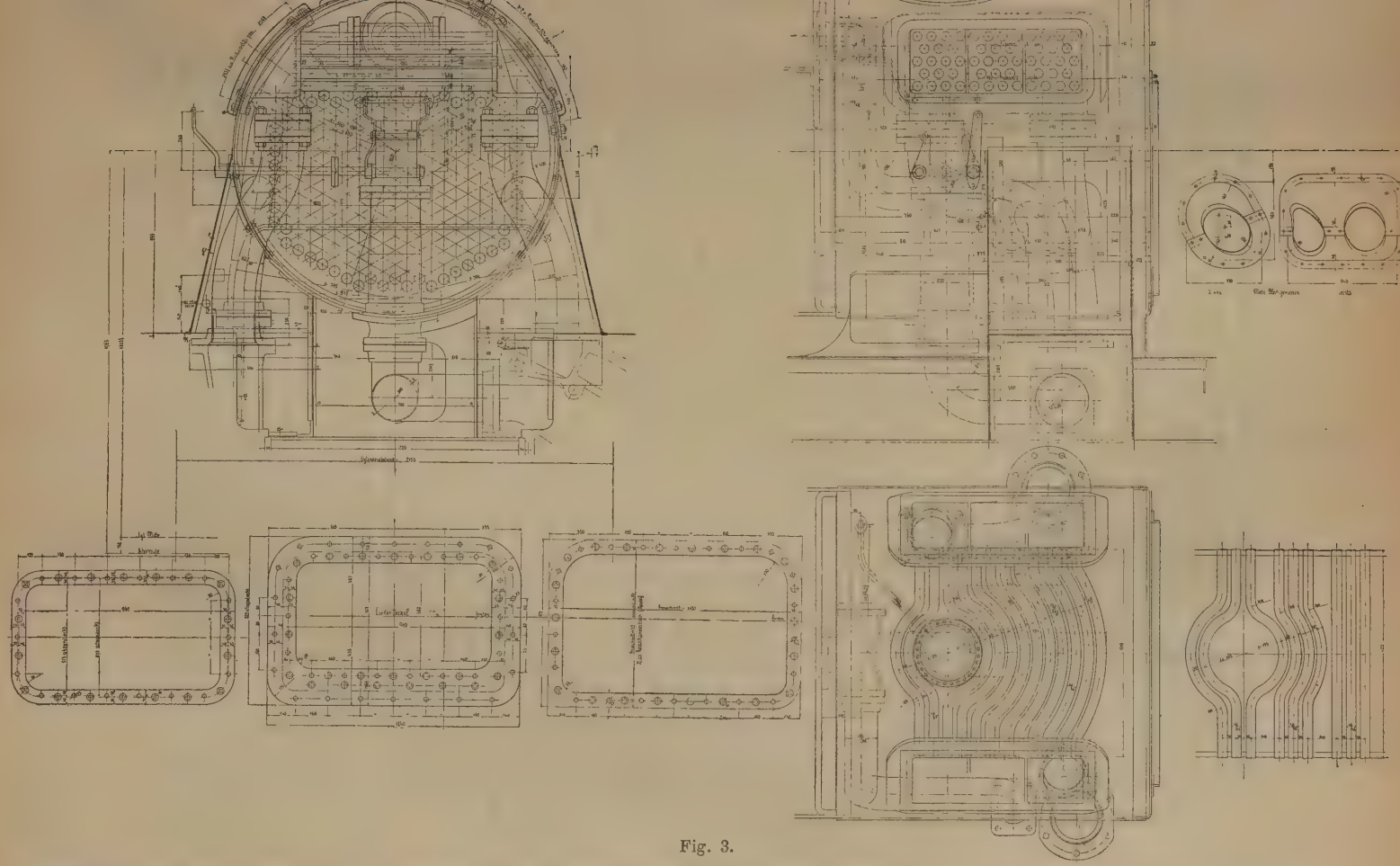


Fig. 3.

Explanation of German terms : Links = Left. — Nur links hinten = Left at back only. — Mitte Blech gemessen = Measured middle of plate. — Rechts = Right. — Ausschnitt = Cut out. — Mitte Rauchkammerblech (Mantel) = Middle of smoke-box plate. — hinten = back. — ker Deckel = Left cover. — Cylinderabstand = Distance of cylinder. — Cylinder Mitte = Middle of cylinder. — Achsmitte = Middle of axle. — 312 *a.* Radius — 804 gemessen = 312*a.* Radius = 804 measured.

This separator and superheater system consists of a chamber which is formed by the smoke-box tube-plate and a third intermediate tube-plate placed in the barrel at a distance of from 1,000 to 1,300 millimetres (3 ft. 3 $^3/_8$ in. to 4 ft. 3 $^3/_{16}$ in.) from the smoke-box tube-plate. In this chamber which contains no water and is filled by the wet steam, this steam is dried and raised to a higher temperature by contact with the hot smoke tubes. In order to increase the circulation of the steam in this chamber, and consequently to utilize the heat of the smoke tubes better, there are one or more intermediate partitions, through which the smoke tubes pass through holes a little larger. This construction has the advantages of a very low weight and of great simplicity; the superheating is it is true not great; the increase in temperature probably only amounts to 40 or 50° C. (72 to 90° Fahr.) and in fact the steam is really only dried. The low superheat however makes it possible to retain the ordinary design of flat slide-valve, as well as to continue the use of the ordinary cylinder oils, which are materially cheaper than the oils suitable for working at high temperatures, with very high flash-point, which must be used if there is much superheat.

Thus this system which heats the steam 80 to 100° C. (144 to 180° Fahr.) less than on the real superheated-steam locomotives (for instance in the case of the Schmidt smoke-tube superheater) thus represents a separator and drier rather than a superheater. A material disadvantage of the system is stated to be the difficulty of keeping the joints of the tubes in the intermediate tube-plate tight; there is also a risk that the tubes in the drying and superheating chamber, which contains no water, may rust; there is no doubt, that putting in the tubes and getting them tight, as well as getting them out again, are troublesome operations; there also seems to be a risk of the smoke tubes becoming damaged by the intermediate tube-plate in consequence of the vibration of the tubes when running. Use and maintenance are made more expensive by the fact that the smoke tubes can only be taken out in pieces, and that these pieces are naturally of less use.

In this system of construction, the indirect heating surface of the smoke tubes, used for steam-generation, is reduced, as a part of the tubes in enclosed in the chamber; this circumstance is however not of much importance, as the front ends of the tubes contribute, as compared with that part of the tubes which is nearer the fire-box, but little to the steam-generation.

Besides this, the Austrian State Railway has equipped three compound locomotives with special receiver superheaters placed in the smoke-box; these heat the steam passing from the high pressure cylinder to the low-pressure cylinder (two different patterns). This arrangement seems satisfactory, but it has been in use too short a time to allow a final conclusion to be reached.

The Pielock superheater, which is also used in Austria on a few locomotives, is generally known. At about the middle of the barrel there is a superheater chamber having the shape of a cube with its corners rounded, through which the smoke tubes pass, and which has tube-plates front and back. This chamber is connected

with the steam dome, and thus as in the Clench design the steam is dried and superheated by contact with the hot smoke tubes. Partitions placed inside the superheater chamber promote the circulation of the steam and its more intimate contact with the tubes; these partitions were at first placed at right angles and afterwards parallel to the direction of the smoke tubes, the latter arrangement being adopted as it was easier to construct. The special appliance shown in figure 5, which consists of a piston valve with three seats, serves for filling the superheater chamber with water while the locomotive is standing idle and for emptying this chamber before the locomotive again starts work.

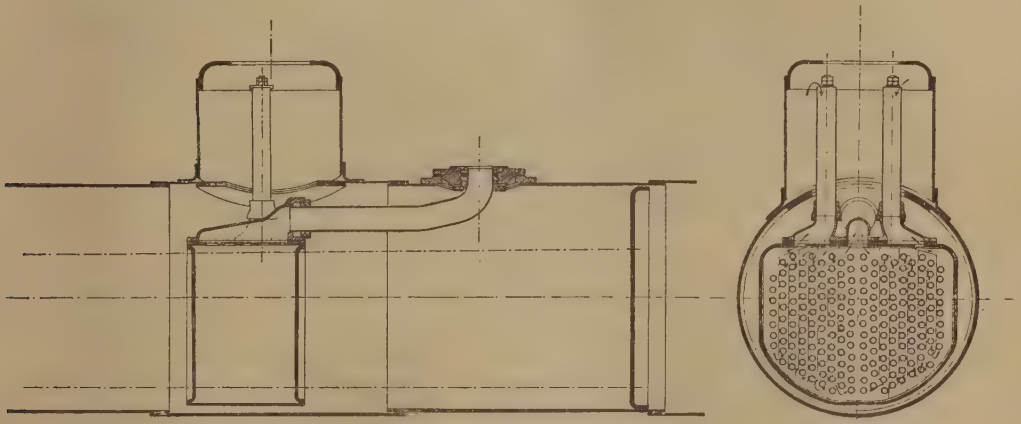


Fig. 4. — Pielock superheater.

As advantages of this system, we may mention the small increase in the weight of the locomotive, as well as the possibility of putting in these superheaters without materially increasing the axle-load or altering their distribution, and moreover the cost of construction is not high; as disadvantages we may mention the difficulty of putting the tubes in and getting them tight, and the maintenance of the tubes, which are liable to become burnt in the superheater chamber; the four tube-plates, which must have holes of increasing diameter, have accordingly twice as many places at which they have to be kept tight, as an ordinary boiler. Tubes which have to be taken out have as a rule to be cut into pieces first, if the tube-plates are not to be loosened by the drawing out. There also seem to be difficulties about the maintenance of the valve device, and its always working properly. The small number of locomotives equipped with this superheater and the short time they have been in use allow no final conclusion to be drawn in this case also; but it may be mentioned that the temperatures of steam attained, although higher than with the Clench system, are lower than those obtained with smoke-tube superheaters.

These two systems, the Clench-Austrian, on the one hand, and the Pielock on the

other, are used by three Austrian railway administrations, and in all cases on 2-cylinder and 4-cylinder compounds of the well-known Gölsdorf type.

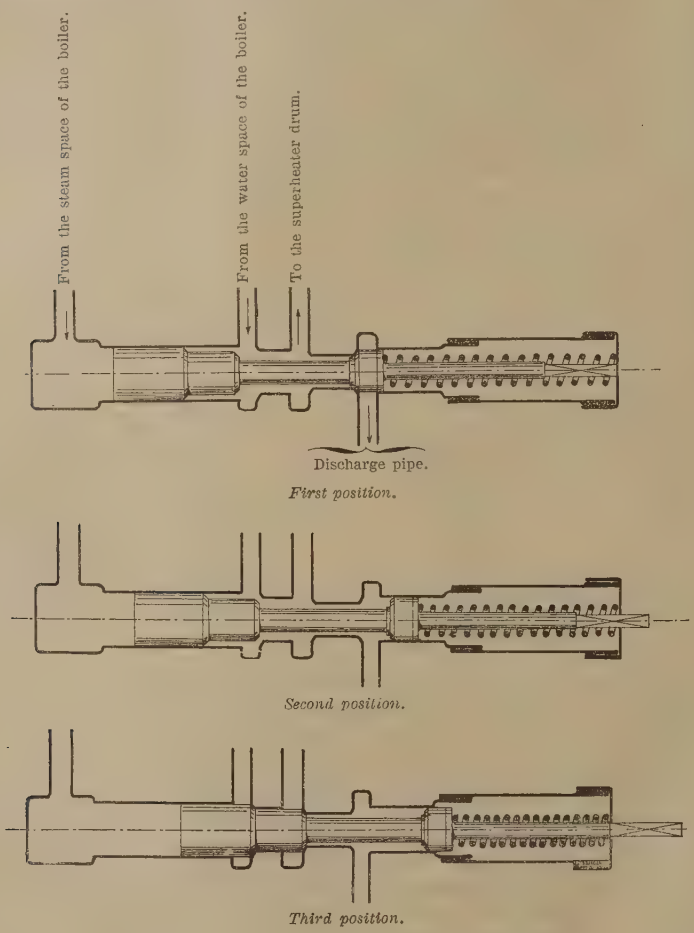


Fig. 5. — Automatic device for Pielock superheater.

All these locomotives have Heusinger (Walschaerts) slide valve gear; the steam is superheated before it enters the one or the two high-pressure cylinders. The slide-valves are of the ordinary flat type, the stuffing boxes usually have metallic packing of the Huhn type, rings with holes and filled with graphite. The piston rods are ground true.

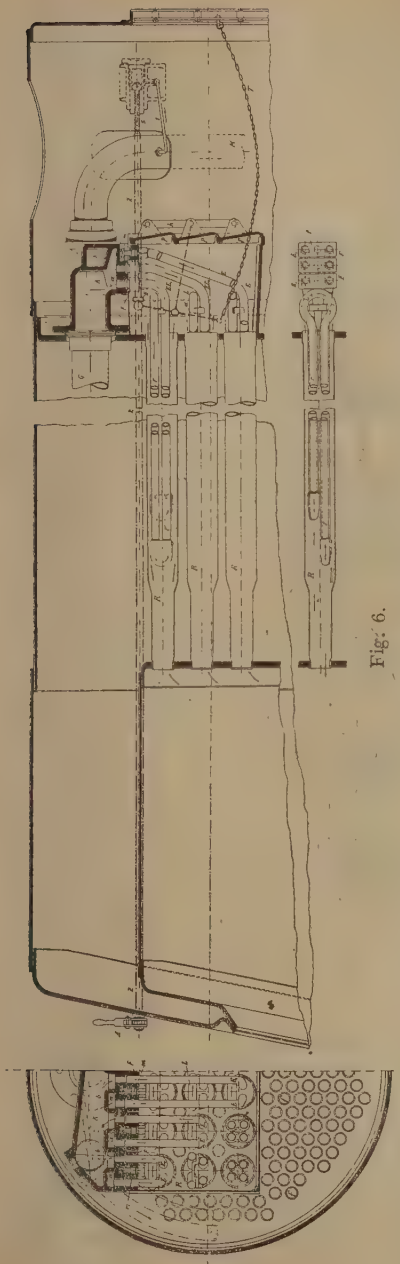


Fig. 6.

In consequence of the low degree of superheat, the locomotives in question, equipped with Pielock superheaters, do not require any special cylinder oil with high flash-point, and consequently the increase in the cost of lubrication is inconsiderable. All the locomotives equipped with Clench and Pielock superheaters are fitted with Friedmann mechanical-plunger lubricators.

The superheater system most extensively applied is that of Schmidt of Wilhelmshöhe (Cassel), in which the superheater elements are inside the smoke tubes, which are made larger.

In the countries this report deals with, this superheater system has found the following applications :

	Locomotives in use.
Austrian State Railway	49
Bukovina Local Railway	3
Lower Austrian Railway	7
Aussig-Teplitz Railway	5
Bosnian-Herzegovinian Railway	12
Austrian North-Western and South-North German Junction Railway (1)	13
Austro-Hungarian State Railway Company (1)	73
Total.	162

	Locomotives now being built.
Austrian State Railway	137
Austrian Southern, Austrian lines	6
— — Hungarian lines	2
Bukovina Local Railway	2
Hungarian State Railway	4
Austrian North-Western and South-North German Junction Railway (1)	10
Total.	161

Thus in 1909 there were altogether 273 locomotives with Schmidt smoke-tube superheater either in use or being built.

(1) The lines of these systems were taken over by the Austrian State.

A detailed description of this design is probably not necessary and it will suffice if the chief details are considered.

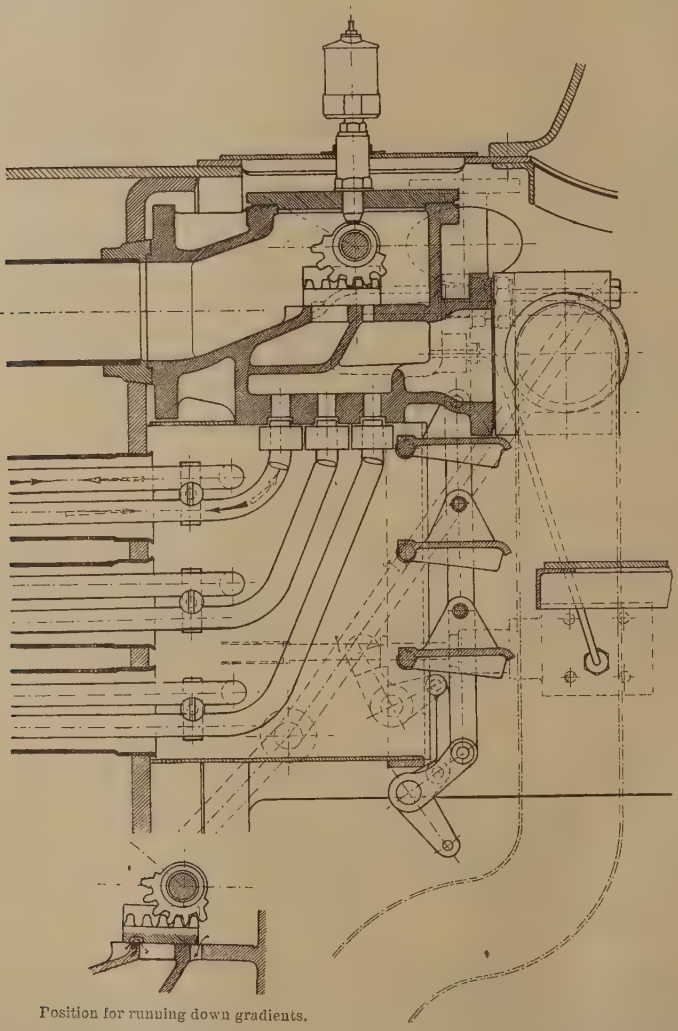


Fig. 7. — The W. Schmidt smoke-tube superheater.

The superheater elements are placed in smoke tubes (fig. 7), which have a larger diameter than ordinary smoke tubes. The superheater elements introduced into

these large smoke tubes each consist of four superheater tubes, which are arranged in pairs side by side and connected at the ends towards the fire-box by bend connectors formed of steel castings, into which they are tightly screwed; at the smoke-box, these tubes end in a steam chamber, which is divided by partitions and is connected by the main steam pipe and through the regulator to the cylinders. That part of the smoke-box which is in front of the openings of the smoke tubes containing the superheater elements, forms a sort of chamber, which can be closed in front by a series of dampers. These dampers when closed prevent the passage of the hot gases through the large smoke tubes, and so prevent the burning of the tubes when the regulator is closed and when accordingly no steam passes through them. These dampers are opened by means of a small auxiliary cylinder, the piston of which operates the mechanism of the dampers; the gear operating the valve controlling the supply of steam to this cylinder is connected with the regulator gear, so that when the regulator is opened the dampers are opened simultaneously. When the supply of steam to the cylinders is stopped, the steam supply to the auxiliary cylinder also ceases, and the dampers drop in consequence of their own weight. Gear operated by hand is also provided by means of which the dampers can be opened, when the locomotive is not in steam, in order to clean the tubes or put in new ones. The superheater tubes are introduced on the smoke-box side in pairs in a sort of sleeve; one bolt is used to secure each pair of tubes, and this facilitates introduction and removal. This system of placing four small-diameter superheater tubes together in one smoke tube, has the advantage that steam and hot gases move twice in the same direction and twice in opposite directions; in this way, the current of steam is subdivided into a large number of smaller parts and thus a more intimate contact with the hot gases results; the heat passing into the smoke-box is not excessive, as in other designs, as indeed was the case with the earlier designs of W. Schmidt himself.

As regards the distribution of the steam on locomotives which are equipped with W. Schmidt smoke-tube superheaters, the two chief systems, the twin type and the compound type, the latter with two and with four cylinders, are used equally in Austria-Hungary; thus the Austrian State Railway with hardly an exception combines the superheater with the compound system, and that with two cylinders in the case of goods and passenger locomotives and with four cylinders in that of express locomotives; these compound locomotives are all of the Gölsdorf type, which is well known, and have piston valves and stuffing boxes of American pattern, very similar to the W. Schmidt pattern, for the high-pressure cylinders and ordinary flat slide valves for the low-pressure cylinders. The other administrations, for instance the Austrian North-Western and South-North German Junction Railway, the Kaiser Ferdinands Nordbahn and the Austro-Hungarian State Railway Company (the lines of all these systems have now been taken over by the State), and also the Aussig-Teplitz Railway have selected the two-cylinder twin design for superheated-steam locomotives; this design is simple to construct and to maintain, is quite satisfactory

as regards power and cost of operation, and is more suitable for the reduced axle-loads which are imposed on some of these administrations in consequence of older and weaker systems of permanent-way construction and bridge construction. One of the chief reasons which at the time led the Austro-Hungarian State Railway Company to give the two-cylinder twin system the preference, when deciding on a type of superheated-steam locomotive, was the possibility to return, with this type, to lower working pressures such as 11·5 and 12 atmospheres, and so approach the happy days of low working pressures, when the maintenance of the boilers did not yet involve all those difficulties, all those long periods of being laid up and that considerable cost of the repairs, which now result from the use of high-pressure boilers. All locomotive engineers know that all these troubles began when locomotive boilers of moderate size and working at pressures of 9 or 10 atmospheres were given up and the large modern high-pressure boilers were adopted The excessive dimensions of the fire-boxes and other details of the boilers can also be reduced when the steam is superheated and consequently better utilized.

The locomotives of the Austrian State Railway are generally fitted with the Heusinger-Walschaerts valve gear, slightly modified to suit the Gölsdorf compound system. This administration also uses a regulator of not quite the ordinary form; the slide covers several ports, a large one through which the steam passes to the superheater elements and a small one, which is intended to supply the superheater elements with a small amount of steam in order to protect them against being burnt when a long distance is run with regulator closed, for instance in descending long gradients; this small port can be kept open when the large is closed; the regulator handle in this case stands a little beyond its normal " closed " position; a small stop, which has to be moved by hand in this exceptional position, ensures that the normal position " closed " is attained. In consequence of this arrangement, a small amount of steam is supplied to the cylinders even when running with regulator closed. The Austro-Hungarian State Railway Company at present (June 1909) possesses 73 locomotives equipped with W. Schmidt smoke-tube superheaters and they started working at various dates from September 1906 onwards. They include :

a) 43 goods-train locomotives with 6 coupled wheels, diameter 1,450 millimetres (4 ft. 9 $^{1}/_{16}$ in.), and 2 carrying wheels . . . . . Series 38
b) 20 locomotives for passenger or goods trains with 6 coupled wheels, diameter 1,550 millimetres (5 ft. 1 in.), and 2 carrying wheels . . . . . — 39
c) 10 express locomotives with 6 coupled wheels, diameter 1,800 millimetres (5 ft. 10 $^{7}/_{8}$ in.), and a leading 4-wheeled bogie . . . . . — 36

All these are twin 2-cylinder locomotives; the first two series have a working pressure of 11·5 atmospheres and the third one of 12 atmospheres. The first two types are the result of the conversion of the wet-steam locomotives already in existence since 1900, with the same underframes and, except as regards the alterations

necessitated by the addition of the superheaters, the same boilers (these alterations only consisted of the alteration of the upper smoke tubes, the shortening of the barrel by 100 millimetres [3 $^{15}/_{16}$ inches] and the removal of the second steam dome). Three types of the wet-steam locomotives exist, suitable for comparison, namely :

One 2-cylinder twin locomotive	Series 37
— — compound locomotive (Gölsdorf system) . . .	— 37·5
— 3-cylinder compound locomotive	— 38·5

The third type, an express type, is converted from a wet-steam 4-cylinder compound of similar arrangement and power. As compared with the wet-steam locomotives, the steam cylinders of the locomotives of the Austro-Hungarian State Railway Company were increased in size as follows : in the case of types *a* and *b* to 520 millimetres (1 ft. 8 $^{15}/_{32}$ in.) as compared with the 490 millimetres (1 ft. 7 $^{5}/_{16}$ in.) of the twin wet-steam locomotives with 2 cylinders, the 520-790 millimetres (1 ft. 8 $^{15}/_{32}$ in to 2 ft. 7 $^{1}/_{8}$ in.) of the wet-steam compounds with 2 cylinders, and the 490-580 millimetres (1 ft. 7 $^{9}/_{32}$ in. to 1 ft. 10 $^{13}/_{16}$ in.) of the wet-steam compounds with 3 cylinders; in case of type *c* to 550 millimetres (1 ft. 9 $^{11}/_{16}$ in.), as compared with the 350-580 millimetres (1 ft. 1 $^{13}/_{16}$ in.-1 ft. 10 $^{13}/_{16}$ in.) of the wet-steam 4-cylinder compounds.

The following diameters were selected for the high-pressure cylinders of the Gölsdorf compound locomotives of the Austrian State Railways which were altered so as to use superheated steam :

Series 206 (2 cylinders)	520	as against	500	millim.	(1 ft.	8 $^{1}/_{2}$	in.	as against	1 ft.	7 $^{11}/_{16}$	in.),
— 110 (4	—)	390	—	370	—	(1 ft.	3 $^{3}/_{8}$	in.	—	1 ft.	2 $^{9}/_{16}$	in.),
— 329 (2	—)	475	—	450	—	(1 ft.	6 $^{11}/_{16}$	in.	—	1 ft.	5 $^{11}/_{16}$	in.),
— 180 (2	—)	590	—	560	—	(1 ft.	11 $^{1}/_{4}$	in.	—	1 ft.	10 $^{1}/_{16}$	in.),
— 60 (2	—)	520	—	520	—	(1 ft.	8 $^{1}/_{2}$	in.	—	1 ft.	8 $^{1}/_{2}$	in.)

of the high-pressure cylinders of the corresponding wet-steam locomotives. The low-pressure cylinders of the superheated-steam locomotives are not altered in diameter.

The superheated-steam locomotives of the Austro-Hungarian State Railway Company have Swedish pistons with three snap rings 20 millimetres ($^{25}/_{32}$ inch) wide and 17 millimetres ($^{11}/_{16}$ inch) thick, which are not intended to support the piston head but only make it tight. The two outer rings have on the outside concentric grooves turned in; small holes 3 millimetres ($^{7}/_{64}$ inch) in diameter are drilled in at equal intervals. As soon as the first or third ring is pressed together at the dead point, the steam enters the space behind the piston ring and stops the pressing together of the ring and its taking off from the cylinder walls again; part of this steam passes through the small holes into the groove, so that the ring is brought again into contact with the cylinder walls very gently, as this movement of the ring is

only produced by its elasticity and the small steam pressure behind it; consequently the wear on the rings is very small. Three piston rings were selected, in order that the middle one might always be certain to keep the cylinder tight. A crosspiece fitted to the ends of the rings keeps the rings from turning.

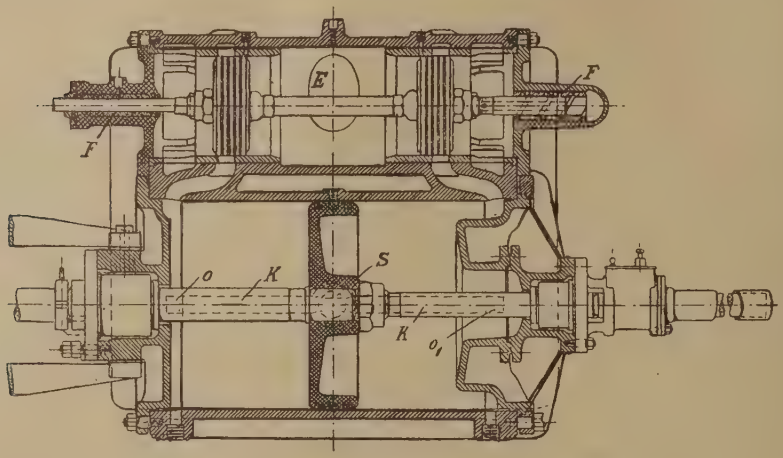


Fig. 8.

The piston rods have the ordinary shape with collar and a taper of 0·72 over 100 millimetres; they are secured by means of a nut with angular thread; the rods are made of crucible steel and ground true; it is also strongly recommended to true the piston rods by grinding when carrying out repairs. One of the most important points is the accurate grinding of the piston rods, which must not be supported by the stuffing boxes. In order to prevent too rapid wear of the metallic stuffing boxes and to ensure that the piston is always in a proper position, the piston rod passes in front through a special guide box, lined with white metal, and it is supported at the back by the cross-head and the slide bars; it is therefore indispensable that the slide bars should always be in the right position; with this object in view, several thin packings (of 0 5 millimetre [$^1/_{64}$ inch]) are interposed when the bars are being fixed; the slide bars can then always be adjusted easily.

The Austro-Hungarian Stale Railway Company has adopted for the piston-rod stuffing boxes the W. Schmidt (Cassel) design. This resembles the American design of the so-called metallic stuffing boxes, but has the advantage that the box containing the packing proper is always cooled by the outer air. This stuffing box has both at its inner and at its outer end a ring with a spherical surface (*a* and *b*, figure 10, which represent the front piston stuffing box). The outer ring is so placed that a vertical plane through its centre will approximately coincide with a vertical plane through

the centre of the packing rings. As the box *h* is pressed against the spherically-shaped ring *b* by the steam and the spring F, fairly strong friction takes place between the smooth surfaces in contact, which is transmitted to the packing rings in case of any lateral displacement of the rod. The position of the ring *b* and of the gap *m* is such that the pressure can be taken up by the packing rings *c* and no jamming occurs; this also prevents the neck ring *d* from being pressed too tightly

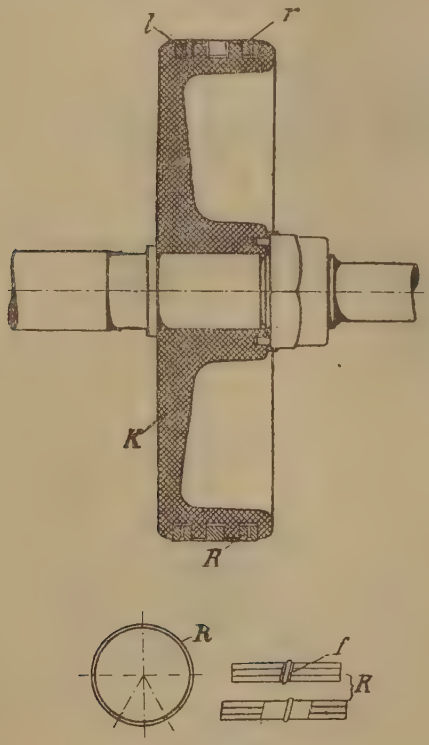
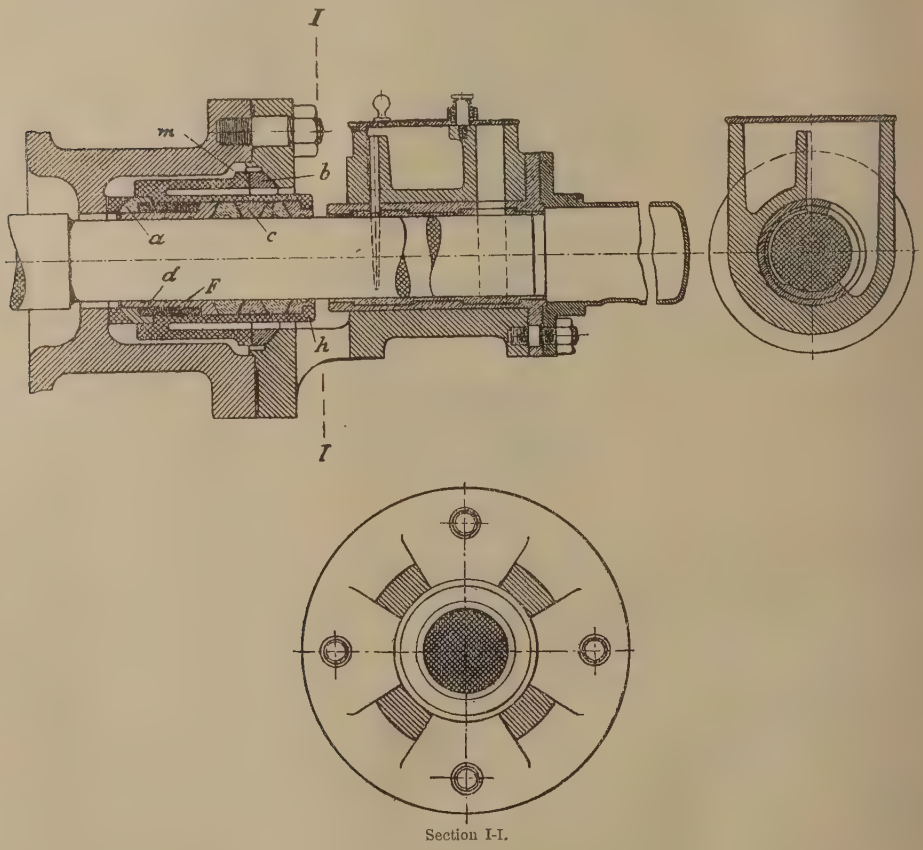


Fig. 9.

against the rod and consequently prevents wear. The spherically-shaped inner ring *a* is only compressed by the weak power of the spring and opposes but little resistance to any lateral movement. The box contains three packing rings made of an alloy; as the outer air is always passing over the stuffing box, the packing rings never become too hot. Of the two neck rings, the inner one is made in the shape of a long box, acting as a labyrinth. The stuffing rings are pressed on by the steam and by the spring; the latter also prevents the rings from becoming displaced

*

when the travel of the piston is reversed. The same figure also shows, besides the front piston-rod stuffing box, the form of the guide box used in front. The piston-rod stuffing box on the back of the cylinders only differs from that in front by its dimensions, which are suited to the larger diameter of the rod.



Section I-I.

Fig. 10.

The packing rings are made of an alloy consisting of 65 per cent of lead, 20 per cent of tin and 15 per cent of antimony; the inner neck ring is made of cast iron, the outer one of bronze (alloy containing 82 per cent of copper, 10 per cent of tin, 6 per cent of lead and 2 per cent phosphor-bronze) and the boxes containing the packing rings are steel castings. The initial tension of the stuffing-box spring is

about 30 kilograms (66 lb.) in the case of the front and 50 kilograms (110 lb.) in that of the back stuffing box.

The administrations whose superheated-steam locomotives this report deals with, use piston valves for both cylinders in the case of the twin locomotives, and for the high-pressure cylinders only in the case of compounds. Two administrations, the Bohemian Northern (now taken over by the State) and the Aussig-Teplitz Railway, use for their piston valves, on six and five locomotives respectively, the closed boxes without spring rings of the Prussian State Railway type; these piston valves are not easy to maintain and it is stated that the boxes become worn quickly. The pattern of piston valve with elastic rings is that used elsewhere nearly generally; these rings suffer but little from wear and spare the boxes. In the case of most locomotives (particularly if of the twin type), the steam enters between the two plates, so that the stuffing boxes do not have to resist the steam pressure of the boiler, but only that of the exhaust; the piston rods therefore only have guide boxes acting as labyrinth packing, which quite suffice and are easy to maintain. The work used up by the friction of the piston valves, the piston rods and the valve rods in the stuffing boxes, is in this arrangement much reduced as compared with the ordinary arrangement; the good results obtained with superheated-steam locomotives as regards power are in part due to the piston valves and the metallic stuffing boxes, which moreover might be used to advantage in this or another shape in the case of wet-steam locomotives.

The piston valve *b*, with a liner 250 millimetres (9 $^{13}/_{16}$ inches) in diameter, consists of two parts fixed one behind the other on a valve rod; each of them is fitted with an elastic ring 69 millimetres (2 $^{23}/_{32}$ inches) in width. The steam-tight spaces *a*, *b*, *c*, to which radially-arranged holes lead, which form a connection between the passage C, and the spaces in question, prevent the ring from being pressed too strongly by the steam entering behind it against the liner, and so the premature wear of the liner is prevented. This arrangement also prevents the elastic ring from being pressed together too much during the period of compression and accordingly any considerable loss of steam is avoided; the dimensions of the spaces and holes are such that the forces acting on the ring are nearly balanced and that it is only the elasticity of the rings which makes them tight. In order to prevent any leakage of steam between the ring R and the follower D or the body K, without clamping the ring which would stop its elasticity from coming into play, the follower D is made somewhat elastic and only screwed tight against the body at its inner edge; its outer edge is pressed against the ring by the pressure of the steam. Should there be any difference of expansion between the ring and the body, the follower can spring and the ring retains its power of movement and is able to assume the correct diameter. Two stops sunk into the body and the follower prevent the turning of the ring, so that the cut F always slides over the broad bar of the port of the liner and is not the source of any leakage. Broad rings are to be preferred to narrow, as the bars of the port of the liner are less affected, and the

risk of sticking or becoming jammed is much reduced. The liners themselves are made of cast iron, only finished by turning and not ground; a pressure of 3·5 to 4 tons (3·4 to 3·9 English tons) is used for putting them in place. The body is a

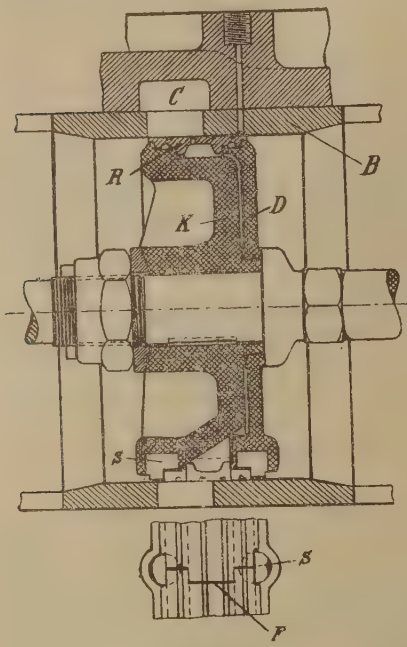


Fig. 12.

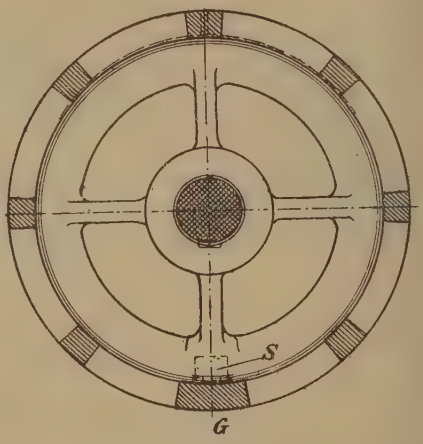


Fig. 11.

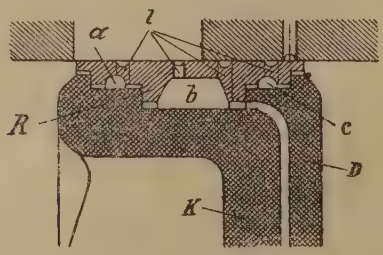


Fig. 13.

steel casting; the rings are cast of special cast iron to which 12 per cent of steel is added; the rings are also only lathe-finished.

The packing rings of the stuffing boxes consist of an alloy which now, after many

experiments, is made of 65 per cent of lead, 15 per cent of antimony and 20 per cent of tin. This alloy gives good results, while that formerly used proved to be too soft.

In order to obtain smooth and silent running and in order to prevent the shaking of the whole locomotive when running with regulator closed, each steam cylinder has a by-pass connecting the front and the back. Gear is provided for opening and closing, from the cab, a rotary valve in this by-pass. The drop in pressure from the boiler to the valve gear is 0·5 bis 0·7 atmosphere. As regards the question how the pressure at admission to the cylinders compares in the case of superheated steam with that observed in the case of wet steam (shape of admission-pressure curve), definite data cannot be given as a sufficient number of diagrams of the superheated steam and of the other locomotives is not available, but it may be deduced from a number of diagrams taken from the saturated-steam express locomotive of the Austro-Hungarian State Railway Company that in the case of the superheated-steam admission line does not drop so soon as in that of the wet-steam locomotive.

The degree of superheat varies with the power; under ordinary conditions it generally amounts to 300 to 320° C. (572 to 608° Fahr.) in continuous working. The temperature is measured by a pyrometer placed in the steam chest (capillary tension thermometer by Steinle and Hartung of Quedlinburg); the thermometer operates an indicator placed in the cab. As yet there are no reliable data showing the connexion between degree of superheat, power and consumption of fuel. At all events it could be determined that high degrees of superheat and reduced coal consumption and water consumption can give more power. Thus a series of experimental runs made with superheated-steam locomotive series 38 of the Austro-Hungarian State Railway Company gave the following results :

—	Light trains.	Heavy trains.	Difference.
Load hauled, in ton-kilometres (in ton-miles)	49,155 (30,062)	67,750 (41,434)	+ 37 per cent.
Mean superheat, in degrees centigrade (in degrees Fahrenheit).	+ 88° (+ 158·4)	+ 99° (+ 178·2)	+ 12·5 —
Consumption of water per 1,000 ton-kilometres, in kilograms (in lb. per 1,000 ton-miles)	175 (630·8)	151 (544·3)	− 13·7 —
Consumption of coal per 1,000 ton-kilometres, in kilograms (in lb. per 1,000 ton-miles)	41·5 (149·6)	38·5 (138·8	− 7·2 —

The water consumption thus becomes reduced as the superheat increases, at very nearly the same rate, but the coal consumption becomes reduced at a slower rate. This is readily explained by the lesser utilization of the coal as the boiler becomes hotter. It must however be mentioned that the results of the superheating depend on the dimensions of the superheater, which have to be suited to the other dimen-

ions of the locomotive and the boiler, the wheels, the cylinders, the grate area, the direct and indirect heating surface. Thus for instance the Austro-Hungarian State Railway Company has among its locomotives superheated-steam express locomotive series 36, with a superheater surface of 38·4 square metres (413·35 square feet), as compared with 33·0 square metres (355·22 square feet) in the case of goods locomotives series 38 and 39; the ratio of superheater surface to heating surface is 1 : 3·8 in the former case and 1 : 4·2 in the latter. In the former case, accordingly, a superheat of 320 to 330° C. (608 to 626° Fahr.) is easily attained, while in the two latter series the superheat as a rule does not exceed 300° C. (572° Fahr.).

As already stated, the working pressures were limited with these locomotives to 12 atmospheres in the case of the express type and to 11·5 atmospheres in that of the goods; this quite suffices for the traffic, and easy and favourable maintenance of the boilers may be expected.

The Austro-Hungarian State Railway Company has made extensive trials with its three similar types of locomotives with six coupled wheels of equal diameter, already referred to, namely :

Series 37	(Wet.-steam).	2 cylinders	twin;
— 37·5	(— —).	2 —	Gölsdorf compound;
— 38	(superheated steam Schmidt).	2 —	twin.

The boilers of the first two are quite the same, and have a working pressure of 13 atmospheres; the boiler of the third type only differs by having the working pressure reduced to 11·5 atmospheres, and by having the superheater added, the barrel being reduced 100 millimetres ($3\,^{15}/_{16}$ inches) in length and the second steam dome being removed. The chief dimensions of these three locomotives are shown in the table hereafter. The experiments were carried out very carefully on a section 100 kilometres (62 miles) long, with gradients varying from 1 to 6·67 per mil, 30 kilometres (18·6 miles) of it being on the flat. The loads, the compositions of the trains and the class of coal used were the same for all the experiments; as regards other conditions, the trial runs were made when these were as nearly the same as possible. The coal used was a mixture of 3 parts of non-caking coal to 1 part of caking coal, with a coefficient of evaporation of 5·5. In order to determine the maximum power of the three types, smaller sections of 4·03 kilometres (2·5 miles) with a gradient of 6·67 per mil, and of 5·07 kilometres (3·15 miles) with a gradient of 4·2 per mil were selected, and run over at the highest speeds attainable with the boilers full and working continuously, so that the results can be considered as showing the greatest continuous power attainable under favourable conditions.

These results of the greatest continuous power on long ascending gradients have shown that at speeds of under 30 kilometres (18·6 miles) per hour the wet-steam compound locomotive is superior to the other two types, but that at speeds of over 30 kilometres (18·6 miles) per hour the superheated-steam locomotive gives more power than the other two wet-steam types.

Table.

Chief dimensions of trial locomotives.	Austrian State Railway.				Aussig-Teplitz Railway.		Austro-Hungarian State Railway Company.		
	Series 60, compound.		Series 110, compound						
	With wet steam.	With steam drier.	With wet steam.	With steam drier.	Wet steam, twin.	Super-heated steam, twin.	Series 37, wet steam, twin.	Series 37·5 wet steam, compound.	Series 38, super-heated steam, twin.
Working pressure, in atmospheres	13	13	15	15	12	13	13	13	11·5
Diameter of barrel, in millimetres (in feet and inches)	1,350 (4′ 5 9/16″)	1,350 (4′ 5 9/16″)	1,584 (5′ 2 3/8″)	1,584 (5′ 2 3/8″)	1,500 (4′ 11″)	1,600 (5′ 3″)	1,480 (4′ 10 5/16″)	1,480 (4′ 10 5/16″)	1,480 (4′ 10 5/16″)
Heating surface, direct, in square metres (in square feet)	10 (107·64)	10 (107·64)	13·7 (147·47)	13·7 (147·47)	13 (139·94)	11·9 (128·10)	11·8 (127·02)	11·8 (127·02)	11·8 (127·02)
— — tubes, — (— —)	134·7 (1,449·95)	110 (1,184·07)	244·15 (2,628·10)	175·7 (1,891·29)	164·5 (1,770·73)	140·4 (1,511·31)	173·2 (1,864·38)	173·2 (1,864·38)	139·4 (1,500·54)
— — superheater, — (— —)	...	24·7 (265·88)	...	58·9 (634·02)	...	50·1 (539·29)	...	...	33 5 (360·60)
— — total, — (— —)	144·7 (1,557·59)	144·7 (1,557·59)	257·85 (2,757·57)	248·3 (2,672·78)	177·5 (1,910·67)	202·44 (2,178·70)	185 (1,991·40)	185 (1,991·40)	184·7 (1,988·16)
Grate area, in square metres (in square feet)	2·7 (29·06)	2·7 (29·06)	4 (43·06)	4 (43·06)	2·9 (31·22)	3·67 (39·50)	2·7 (29·06)	2·7 (29·06)	2·7 (29·06)
Cylinders, diameter, in millimetres (in feet and inches)	520 (1′ 7 11/16″)	520 (1′ 7 11/16″)	2 × 370 2 × (1′ 2 9/16″)	2 × 370 2 × (1′ 2 9/16″)	500 (1′ 7 11/16″)	540 (1′ 9 5/16″)	490 (1′ 7 5/16″)	520 (1′ 7 11/16″)	520 (1′ 7 11/16″)
Length of stroke, — — —)	740 (2′ 5 1/8″)	740 (2′ 5 1/8″)	2 × 630 2 × (2′ 13/16″)	2 × 630 2 × (2′ 13/16″)				790 (2′ 7 1/8″)	
Number of coupled axles	632 (2′ 7/8″)	632 (2′ 7/8″)	720 (2′ 4 3/8″)	720 (2′ 4 3/8″)	650 (2′ 1 5/8″)	630 (2′ 13/16″)	650 (2′ 1 5/8″)	650 (2′ 1 5/8″)	650 (2′ 1 5/8″)
— of carrying axles	3	3	3	3	3	3	3	3	3
Diameter of coupled wheels, in millimetres (in feet and inches)	1	1	2	2	2	2	1	1	1
— of carrying — — — —)	1,258 (4′ 1 1/2″)	1,258 (4′ 1 1/2″)	1,780 (5′ 10 1/16″)	1,780 (5′ 10 1/16″)	1,650 (5′ 5″)	1,620 (5′ 3 13/16″)	1,440 (4′ 8 11/16″)	1,440 (4′ 8 11/16″)	1,440 (4′ 8 11/16″)
Adhesive weight, in metric tons (in English tons)	830 (2′ 8 11/16″)	830 (2′ 8 11/16″)	995 (3′ 3 3/16″)	995 (3′ 3 3/16″)	999 (3′ 3 5/16″)	1,000 (3′ 3 3/8″)	995 (3′ 3 3/16″)	995 (3′ 3 3/16″)	995 (3′ 3 3/16″)
Weight in running order, in metric tons (in English tons)	43·1 (42·4)	42·3 (41·6)	42·9 (42·2)	42·9 (42·2)	40 9 (40·3)	40·19 (39·6)	40·5 (39·9)	40·6 (40)	42 (41·3)
Weight empty, in metric tons (in English tons)	53·5 (52·7)	52 (51·2)	69 (67·9)	69·4 (68·3)	59·7 (58·8)	65·78 (64·7)	51·4 (50·6)	52·3 (51·5)	53·4 (52·6)
	43·3 (42·6)	47·8 (47·0)	61·8 (60·8)	63·4 (62·4)	54·5 (53·6)	60 (59·1)	45·4 (44·7)	46·3 (45·6)	47·6 (46·8)

The mean consumption of water per 1,000 ton-kilometres hauled was as follows :

Wet-steam twin locomotive	207 kilograms	(746 lb. per 1,000 English ton-miles).	
— compound locomotive . . .	187 —	(674 —	— —).
Superheated-steam compound locomotive	163 —	(588 —	— —).

Thus the superheated-steam compound used 21·2 per cent less water than the wet-steam twin locomotive and 12·8 per cent less than the wet-steam compound locomotive.

The mean consumption of coal per 1,000 ton-kilometres hauled was as follows :

Wet-steam twin locomotive	40 kilograms	(144 lb. per 1,000 English ton-miles).	
— compound locomotive . . .	37·5 —	(135 —	— —).
Superheated-steam compound locomotive.	32 —	(115 —	— —).

Thus the superheated-steam compound used 20 per cent less coal than the wet-steam twin locomotive and 14·7 per cent less than the wet-steam compound locomotive.

The mean quantity of coal burnt per square metre of grate area per working hour (with regulator open) was as follows :

Wet-steam twin locomotive	388 kilograms	(79·5 lb. per square foot).
— componnd locomotive	381 —	(78·0 — —).
Superheated-steam compound locomotive. . . .	304 —	(62·3 — —).

These figures show that the superheating of steam presents the great advantage, that the boiler has to do materially less work for the same amount of power.

The administration of the Austrian State Railway has made trials with its locomotives with steam-drier as compared with wet-steam locomotives of the same design. The excellent working results obtained during a year of trial were as follows :

Saving of fuel of compound locomotive series 60 with six coupled wheels and two carrying wheels and steam-drier as compared with the same compound locomotive series 60 using wet steam :

Per 1,000 ton-kilometres	9·8 per cent.
Per kilometre run	15·2 —

The same administration made trials in May 1908 with two express locomotives, 4-cylinder Gölsdorf compounds, with six coupled wheels, two leading and two trailing carrying wheels (*Pacific* type), one of which was equipped with the steam-drier ; the results obtained showed that the steam-drier locomotive consumed 10·5 per cent of water and 13·7 per cent of coal per unit of work less than the wet-steam locomotive.

In February 1907 the Aussig-Teplitz Railway ran trial express trains hauled by two different locomotives; the first was a wet-steam twin express locomotive with a leading bogie and six coupled wheels, the second a superheated-steam twin express

locomotive (Schmidt smoke-tube superheater) with six coupled wheels and two leading and two trailing carrying wheels (*Pacific* type). It was ascertained that the economy of the superheated-steam type as compared with the wet-steam type amounted to 28·9 per cent as regards water and 20·5 per cent as regards fuel.

It must however be mentioned that in a former experiment made with the same locomotives, nearly the same saving in water was observed, but only a very small saving in coal. This result is readily explained by the fact that the work done by the locomotive, as regards both speed and load, was much less than in the subsequent experiment; the results given of the high coal consumption are probably caused by the fact that a comparison is being made with a boiler working under excessive conditions, as the coefficient of evaporation of one and the same coal was one-third higher in the case of the wet-steam locomotive than in that of the superheated-steam locomotive; the first is thus working with great difficulty and a considerable amount of water is carried over.

The preceding table gives the chief dimensions of the superheated-steam steam-drier locomotive and those of the wet-steam locomotive with which it has been compared above.

As against the saving effected in water and fuel by the superheated-steam locomotives, they consume more lubricant. The oil used for lubricating superheated-steam cylinder and piston valves must have a very high flash-point and costs about 30-50 per cent more than the ordinary cylinder oils used for wet-steam locomotives. The amount of oil consumed in the cylinders and piston valves of superheated-steam locomotives is also rather greater, per unit of work, than in the case of the ordinary types. It may, however, be assumed that if the oil pumps are adjusted so as to give an ample but not extravagant supply of oil, the cost of the lubrication of the cylinders and piston valves of superheated-steam locomotives is scarcely 30 to 50 per cent higher than is the cost of wet-steam locomotives. In Austria, this extra cost will as a maximum reach 5 to 6 kronen per 1,000 locomotive-kilometres (5*s.* 8*d.* to 8*s.* per 1,000 locomotive-miles), so that this will amount in the year to about 350 kronen (£14.11*s.*) in the case of an express locomotive and to 200 kronen (£8.6*s.*) in that of a goods locomotive. These amounts, which correspond to annual coal consumptions of 30 to 35 and 20 to 25 tons respectively, of coal of medium value, are insignifiant as compared with the saving in fuel which may reach as much as 180 and 150 tons respectively in the two classes of locomotives; and to this we have to add the considerable saving in water, representing an amount which cannot very well be estimated as the cost of water varies very much.

As regards the maintenance of superheated-steam locomotives, the reporter only has available the results which refer to the locomotives of the Austro-Hungarian State Railway Company (now taken over by the Austrian State). The other administrations considered in this report have only supplied very few data as their superheated-steam locomotives have only been in use a short time.

The superheated-steam locomotives of the Austro-Hungarian State Railway

Company, the behaviour and maintenance of which will be considered below, are all equipped with Schmidt smoke-tube superheaters. There are 73 locomotives, the first of which was set to work in November 1906; thus the oldest have been in use nearly three years. During this time, the superheater elements and their connections have kept in fair condition, and nothing has yet had to be replaced; the bends show signs of wear and of becoming burnt. The only renewals which took place were those of the asbestos-copper rings used at the joints of the superheater tubes and the steam chamber; these renewals are required after every 12 or 18 months and carried out when the boilers are cleaned out. It is absolutely necessary to clean the large smoke tubes in which the superheater elements are placed, regularly. This is done after every longer run (200 to 1,000 kilometres [124 to 620 miles]), according to the work the locomotive has done. These smoke tubes are cleaned by blowing them out with air and steam (the Schmidt blowing-out device). If this regular cleaning were omitted, crusts of soot and cinders would soon form on the superheaters and connexions, the soot would then catch fire and the tubes and connections would become burnt. The maintenance of the dampers regulating the superheating presents no difficulty; no renewals have yet been necessary. The automatic gear for opening the dampers could not be kept tight on some locomotives; the cause being the rodding attached to the piston of the small cylinder and its vibration; as yet no complete remedy has been found and the question is under investigation.

A short time after some of the superheated-steam locomotives had started running, difficulties turned up in keeping the large smoke tubes tight; but they were soon overcome and have not occurred since. Condensed water has collected in the steam chamber in the smoke-box; this inconvenience was overcome by putting in an automatic ball valve.

Smoke tubes were used on a number of locomotives which have a length of 500 millimetres (1 ft. 7 $^{11}/_{16}$ in.) (about one-ninth of their whole length) at the smoke-box end corrugated (the Pogany system); the deposit of scale is not greater at this part than at the smooth parts; these tubes have given good results and remain tight properly.

It has been asserted that the fire-box tube-plate of the superheated-steam locomotives would show a tendency to bend along the line between the upper larger smoke-tubes and the other smaller ones, caused by the difference between the stresses produced in the tube-plate by the set of large and the set of small smoke tubes; now it is difficult to assert that this phenomenon will not appear after a number of years, but at present nothing can be seen of it; the tube-plates have remained even, and their state is by no means inferior to that of similarly-worked boilers of wet-steam locomotives used the same length of time.

The Schmidt piston valves used by the Austro-Hungarian State Railway Company, together with their rings, work very well; it is true that up till now some rings have had to be renewed on account of broken inner ribs, but this was always caused by porous material. The wear of the rings on their faces is very slight; when it exceeds

0·3 millimetre ($^1/_{64}$ inch), in which case the ring is also already weakened at its circumference, it is renewed. This has only occurred in the case of the express type (on 10 locomotives in 15 months altogether 18 rings). The grooves and small holes in the piston valve rings only become clogged to a small extent by oil residues and other deposits; all that is necessary is to blow steam through them from time to time. Increased leakage at the piston after it had been some considerable time in use was observed in a few cases, but was easily remedied. The boxes of the piston valves are quite secure and do not leak; the bars show hardly any wear; no oil residues interfering with the passage of the steam have yet been observed; but between the valve rings and the body of the piston and between the latter and the cover oil-crusts are formed which are however easily scraped off. The good maintenance of the piston valves and the rareness of any defect have made it possible to consider the extension of the duration of the trials, which had at first from motives of caution been fixed at three months, to six months.

The wear of the piston rings in the steam cylinders is about the same as in the case of wet-steam locomotives, and they are renewed when the rings become too weak and lose their spring, or when the gap between the ends of the rings and the ring lock becomes too great (2 millimetres [$^5/_{64}$ inch] are admitted); on the average, the rings are renewed in the express locomotives in from six to eight months and those in the goods locomotives in from twelve to eighteen months. It has happened in a few cases that the locking piece at the ring ends has become loose and fallen out; to remedy this two different new shapes are being tried. The grooves and holes of the rings do not become clogged with dirt; the bodies of the pistons have not yet become loose.

In the locomotives first built, the diameter of the bodies of the pistons was only 3 millimetres ($^1/_8$ inch) less in diameter than the cylinder bore, and turned off centrically; it sometimes happened that the body came into contact with the walls of the cylinder at the bottom and rubbed. By reducing this diameter by 1 millimetre ($^3/_{64}$ inch) and turning it off eccentrically so that the body of the piston has a play of 3 to 3·5 millimetres ($^1/_8$ to $^9/_{64}$ inch) at the lower side, this inconvenience was eliminated.

The piston-rod stuffing boxes, of Schmidt design, as a rule give good results; but they require a certain amount of supervision and also careful maintenance. As a rule, the front side keeps in better condition in consequence of better guidance and the less wear of the guide box; the packing rings at the back of the cylinder have to be renewed two or three times as frequently as those at the front. The life of the rings depends on the kind and amount of work the locomotive has to do and on the quality of the alloy used; it may as a rule be assumed that a set of packing rings lasts at least five and at most ten months; the expenditure incurred for this purpose amounts to about 28 to 31 kronen (£1.3*s.* 3*d.* to £1.5*s.* 10*d.*) per year. The packing rings are as a rule renewed at the general overhaul (every six months).

The other parts of the stuffing boxes, the neck bushes, the springs and the glands

have as yet given no appreciable trouble; in a few cases springs broke and glands became deformed; faulty springs are replaced, damaged or broken packing rings are recast.

The pressure compensation device, the cylinder safety valves and the other details of the superheated-steam locomotives which have not been specially described, call for no particular remark; the cylinder valves must, it is true, be cleaned out at least once a month, as they become dirty and the spring action is interfered with.

In the appended table particulars are given about the maintenance of the different details of the superheated-steam locomotive.

It must however be admitted that the use of superheated-steam locomotives involves greater care both as regards supervision and periodical examination than is the case with the ordinary wet-steam locomotives. The cost of these operations is consequently also greater, and the extra expenditure may be assumed to amount to about 300 kronen (£12.9*s*. 7*d*.) per locomotive per year. But when we consider that in the case of the superheated-steam locomotives the boiler is less taxed, as is also the engine in consequence of the piston valves and the easy running, we arrive at the final result that the cost of maintenance of the superheated-steam locomotive is certainly equal, and probably less than that of the wet-steam locomotive, and that consequently the working expenses benefit by the saving effected in fuel and in water and the advantage of greater power, if we deduct from this the small increase in the cost of lubrication.

III. — Feed-water heaters.

Subject VI, littera B, also deals with the question of feed-waters heaters. As all of the administrations of the railways of the countries with which this report deals use injectors, the only way in which feed-water can be heated is by steam admitted into the injector. In any case, with lifting injectors and a lift of about 1·5 metres (4 ft. 11 in.), it is hardly possible to have the water in the tender at a higher temperature than 30 or 35° C. (86 or 95° Fahr.), or else the injector fails to act. The modern locomotives of the Austrian State Railway, which have lifting injectors with a lift of over 1·5 metres (4 ft. 11 in.), have accordingly added a branch to the water supply pipe, through which cold water can be introduced should the injector fail to act in consequence of too high a temperature.

We have not heard of any other new devices for heating the boiler feed-water

CONCLUSIONS.

1° Water tubes are used in the countries which this report deals with, only in the form of water-tube fire-box boilers. This type of boiler has as yet not been used and tried extensively enough and long enough to make it possible to form a conclusive opinion. In any case this type is an interesting novelty.

2° The use of appliances for drying and superheating the locomotive steam is advantageous; the use of superheated or at least of dried steam is much to be recommended, for it enables increased power to be obtained with but a little increase in weight and with a reduced water and coal consumption per unit of power. The advantages which can be realized seem to increase with increased temperature of the steam and increased power (speed and load).

In the case of locomotives with driving wheels having a diameter of about 1,500 millimetres (4 ft. 11 in.), speeds of over 35 kilometres (21·7 miles) per hour are probably the best.

The increased cost of construction and maintenance (it is as yet doubtful whether there is any increase in the latter) and the increased cost of lubrication are more than counterbalanced by the reduced fuel and water consumption.

The use of the twin action in the case of superheated steam makes it possible, while obtaining sufficient power and using a boiler which is not of excessive size, to use lower pressures, and this facilitates the maintenance of the boiler.

It is at present very difficult to forecast which of the different arrangements will be best:

Steam drier with moderate superheat and compound working; or steam considerably superheated and twin working; or steam considerably superheated and compound working; present experience seems to show that the two former systems are about equal in merit.

The running and the maintenance of superheated-steam locomotives present no difficulty.

APPENDIX.

Table showing the behaviour of the most important details of the superheat-steam locomotives, with Schmidt smoke-tube superheater, of the Austro-Hungarian State Railway Company.

Séries 38, goods locomotives. . . . . } with 6 coupled wheels and 2 leading
— 39, passenger and goods locomotives . . . . } carrying wheels.

— 36, express locomotives . . . . . } with 6 coupled wheels and a leading 4-wheel bogie.

3 locomotives of series 38, are in use since October 1906.
20 — — 39, — — June 1907.
10 — — 36, — — April 1908.
18 — — 38, — — July 1908.
22 — — 38, — — February-March 1909.

Total 73 locomotives.

Index number.	NAMES OF PARTS.	RESULTS.
	A. — *Superheater.*	
1	Burning of superheater tubes or of bend connectors.	Has not yet occurred. No superheater tubes have yet been renewed.
2	Scouring the smoke and superheater tubes by the bend connectors.	Such scouring has been observed, but is hardly appreciable.
3	Keeping the joints of the superheater tubes tight : *a*) at the bend connectors; *b*) at the flanges at the chamber.	No trouble as yet.
4	Renewals of copper-asbestos rings between flanges and chamber.	They are renewed every year, at the inspection of the superheater, when the elements are taken out; the old rings cannot be used again.

Index number.	NAMES OF PARTS.	RESULTS.
	B. — *Smoke tubes.*	
1	Keeping the smoke tubes tight generally.	As a rule there was no trouble. Repairs during the carlier periods of use were only necessary in a very few cases.
2	Behaviour of smoke tubes corrugated at the end. Deposit of scale in the corrugations; cleaning them and removing the scale.	Good. Scale was only deposited in thin, uniform layers. The total removal of the scale is only possible when the tubes are taken out; as yet this has not been necessary.
3	Cleaning the tubes by the steam-blast device.	This is done after every 200 to 1,000 kilomètres (124 to 620 miles), according to the work done by the locomotive and the class of coal burnt. It is probable that the cleaning is not quite thorough, but it suffices for the superheating action.
4	Influence on the fire-box tube plate, between the two sets of tubes (bends, cracks).	None observed.
	C. — *Regulator devices.*	
1	Automatic device for operating the dampers.	Interferes with the outlook of the driver. The pistons on nearly all the locomotives begin to leak after a short time, and consequently frequently require regrinding.
2	Superheater dampers.	Act perfectly and do not get out of order.
	D. — *Piston valve.*	
1	Life of piston-valve rings.	As a rule these wear well. Fractures of the inner rib (at the circumference), have occasionally occurred. Cause : porous metal.
2	Wear of surfaces of rings and piston body or follower.	Very slight; when the play amounts to 0·3 millimetre ($^1/_{64}$ inch) the rings are renewed. Up till now 18 rings have been renewed.
3	Clogging of grooves and holes in the rings.	Unimportant; it has as yet always been removed by blowing steam through.
4	Rotation of piston valve rings.	Has not yet happened.
5	Wear of bars at ports of valve chest.	No measurable wear has as yet been observed.
6	Leakage or loosening of piston-valve stuffing boxes.	Has not yet happened.

Index number.	NAMES OF PARTS.	RESULTS.
	D. — *Piston valve.* (Continued.)	
7	Formation of oil crusts at the piston valve and boxes.	Only in very thin layers at the rubbing surfaces of the ribs of the rings, the body of the piston and the follower, and above on the surface of the ring; this is scraped aff.
8	Clogging of ports by oil crusts.	As yet the ports were not found appreciably obstructed or dirtied.
	E. — *Steam cylinder.*	
1	Renewal of steam-piston rings.	Takes place after 15 to 18 months in the case of goods locomotives and after 6 to 8 months in the case of express locomotives.
2	Wear of piston-ring grooves.	Very slight.
3	Behaviour of locking pieces for rings.	Occasional loosening; some have come out. Their design is being altered.
4	Clogging of grooves and holes in the rings.	Quite insignificant.
5	Piston body working loose.	Has not yet happened.
6	Formation of oil crusts in the cylinder and on the cylinder covers.	Thin oil crusts are only formed on the cylinder covers.
	F. — *Piston-rod stuffing boxes.*	
1	Life of packing rings. Consumption per locomotive per year. Life of neck bushes, glands and springs.	The consumption of packing rings varies considerably according to the work and operation of the locomotives. The front stuffing-box rings last 2 to 3 times as longs as the back ones. The number of sets (of three) consumed per year and per locomotive amounts to :

	Goods locomotive.	Express locomotive.
front box . . .	2 to 3	5
back box . . .	2 to 7	15 [1]

[1] This applies to express locomotives running 6,280 kilometres (3,902 miles) per month.

Index number.	NAMES OF PARTS.	RESULTS
	F. — *Piston-rod stuffing boxes.* (Continued.)	
2	Life of neck bushes, glands and springs.	The neck bushes become worn but little, and are recast; the glands become deformed in some cases and are then readjusted or renewed. The springs stand well; if required they are resprung.
	G. — *Pressure-compensation and safety valves.*	
1	Behaviour of pressure-compensation device.	Works perfectly
2	Behaviour of safety valves on cylinders.	The safety valves must be cleaned at least once per month. There is no trouble. The springs act well.

[621 .133.3 & 621 .133.7]

REPORT N° 8

(Austria-Hungary, Rumania, Bulgaria, Servia and Turkey)

By Johann PAPP,

COUNCILLOR OF STATE,

CHIEF INSPECTOR AND HEAD OF THE LOCOMOTIVE DEPARTMENT OF THE HUNGARIAN STATE RAILWAY.

The list of questions referring to subject VI, *A* and *C*, is the same as that of the English reporters, Messrs. Archbutt and Fowler, and is given at the end of this report.

The numbers of the headings in the report refer to the numbers of the individual questions as they appeared in the list of questions sent out.

LITTERA *A*.

Boilers with smoke tubes; precautions in constructing and maintaining tubes and tube-plates.

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1. Types of boiler. — As a rule the boilers of the more recent types of locomotives are round-topped. Belpaire boilers are occasionally to be found on older locomotives, as well as flat tops of the Becker and other similar types. On the lines of the Austrian State Railway and of the Hungarian State Railway, there are however also some boilers of the Brotan type, with water-tube fire-box, in use, but the trials made with them have not yet been completed. The results so far obtained are favourable; the boiler can do considerably more work and the small damage which has occurred at a few tubes is so far not of importance.

*

2. Stiffening the fire-box crown. — The stiffening of the fire-box crown is in recent times effected exclusively by means of stay-bolts which, apart from a few exceptions, are not radial to the top of the boiler, but vertical to the fire-box crown. Usually the front parts of the fire-box crown, together with the two front rows of stay-bolts, are fitted with strap bars, in order to provide for the expansion of the tube-plate, and prevent cracks from forming in the bends of the tube-plate. The front two rows of the stay-bolts are usually made movable.

On locomotives of older type roof bars are still frequently found.

Quite recently, fire-boxes of the Polonceau type are again being used more extensively, which require no particular stiffening at the crown by means of stay-bolts.

The advantage of stay-bolts as compared with roof bars consists in the easier cleaning of the roof of the fire-box; but this system of construction has the disadvantage of less movability; this can, however, be remedied, at least in part, by the use of flexible stay-bolts. The roof bars have the advantage of greater movability of the roof, as well as that of easy removal, to enable the boiler to be examined; but they have the disadvantage that scale is more apt to deposit and that it is consequently more difficult to clean the upper part of the fire-box. The Polonceau fire-box, with which the Hungarian State Railway has now equipped 235 locomotives with good results, has the advantage, in addition to easy cleaning, that no stay-bolts have to be used; the ribs of the fire-box crown also add to the heating surface. The only disadvantage that can be named is the difficult construction of the constituent parts.

3. Cylindrical fire-boxes. — Cylindrical fire-boxes are not used. The Hungarian State Railway has at one time built locomotives for secondary railways with half-round arched covers of corrugated plate, on the Hasswell system. As in consequence of occasional want of water cases occurred in which this crown collapsed and even became torn, the Hasswell crowns were provisionally secured by means of stay-bolts to the top of the boiler, and are being gradually replaced with Polonceau fire-box crowns. The advantage of the arched fire-box crown merely consisted in the fact that hardly any scale became deposited there.

4. Combustion chambers. — Boilers with this arrangement are entirely absent.

5. Fire-box material. — The material generally used for fire-boxes is copper. Trials of iron fire-boxes have been made on several railways, and some are still the object of trial at present. For instance, the Austrian State Railway has a number of ingot-iron fire-boxes and also iron water-tube fire-boxes of the Brotan system. Both give good results: the trials have now been going on four to five years, but as yet no conclusive opinion has been arrived at. The Hungarian State Railway has three Brotan boilers in use, and is having thirteen more built; but in this case also the trials are not yet concluded. The latter administration tried five fire-boxes made

of ingot-iron a number of years ago; these had, however, to be taken out after they had been in use a comparatively-short time and replaced by copper fire-boxes, because they showed cracks and serious rusting in their lower portions. A fire-box is at present being fitted with a Polonceau crown of ingot-iron.

The iron fire-boxes also did not give good results on the Austrian North Western Railway, and also had to be taken out because cracks formed.

The Austrian Southern Railway, a number of years ago, tried some ingot-iron fire-boxes, made of corrugated plate, on the Hasswell system; and also for a short time some copper fire-boxes with the tube-plate made of ingot-iron. The results obtained were, however, unfavourable, as cracks and fractures appeared, in some cases already during the fitting, in others while in use; it was found that the fuel used (coal) acted on the material and produced a chemical change which affected the strength and durability of the plate materially. These trials were accordingly stopped, and copper fire-boxes were then used.

6. Fire-doors. — The fire-holes have as a rule a round shape; more rarely they are oval. With modern large and wide fire-boxes they are also very frequently rectangular, with doors sliding sideways. In some cases, the rectangular door frames have their corners rounded. The doors are sometimes solid, and sometimes have sliding or circular air grids, which are operated either automatically or by hand.

The diameter of round fire-doors varies between 340 and 400 millimetres (between 1 ft. 1 $^3/_8$ in. and 1 ft. 3 $^3/_4$ in.) according to size of boiler; oval doors, such as are used on the Southern Railway, have horizontal and vertical axes of 380 and 330 millimetres (1 ft. 3 in. and 1 ft. 1 in.) respectively. The Austrian State Railway has adopted on its new locomotives the Marek fire-door with air admission as its standard. The Hungarian State Railway has 40 locomotives with such doors; the newer locomotives of the Aussig-Teplitz Railway are also fitted with Marek doors.

The Austrian North Western Railway has recently been using a door domed outwards, with slots, made of thin cast-iron. The slots can be closed by a sliding register. The object of the doming is to obtain an increased supply of air, for the purposes of smoke consumption.

The connection between the inner fire-box plate and the back plate, at the fire-hole, is either made by a frame, which is riveted on, or, in the newer locomotives, the inner fire-box plate and the back plate are suitably bent and riveted together direct (the Webb fire-hole). In this case a ring-shaped plate is often screwed to the inner side of the fire-hole, while in the case of fire-holes with frames a protective plate is only secured to the lower half of the fire-hole in order to prevent any damage by the coal shovel or fire-pick.

7. Relative dimensions of the grate. Drop grates and rocking grates. — The relative dimensions of the grates vary within very wide limits. On most of the railways, no definite figures are fixed for the ratio between the total grate area and the

useful grate area, and between the latter and the heating surface of the tubes; these only depend on the kind of coal used. As a rule, the useful grate area is about 30 to 50 per cent of the total grate area, and the total heating surface of the smoke tubes is about 40 to 80 times the total grate area. These ratios, however, vary widely from these limits on some of the railways.

On the locomotives of the Austrian Southern Railway, the ratio of total grate area to useful grate area is 1·66 : 1 on nearly all locomotives. This ratio is only altered if it is a question of using a special kind of coal. The ratio of total grate area to area of cross-section of tubes varies between 11 : 1 and 13·20 : 1.

Two types of locomotives of this railway (Hungarian lines) have the following dimensions :

Type 1-C :

Total grate area	2·7 square metres	(29·06 square feet).
Useful —	1·75 —	(18·84 —).
Heating surface of smoke tubes .	132·1 —	(1,421·97 —).

Type 2-B :

Total grate area	3·0 square metres	(32·29 square feet).
Useful —	1·96 —	(21·10 —).
Heating surface of smoke tubes .	141·6 —	(1,524·22 —).

On the Aussig-Teplitz Railway the ratios in question are as follows : total grate area to heating surface of smoke tubes, from 1 : 56 to 1 : 81; useful grate area to the same surface, from 1 : 105 to 1 : 147.

The locomotives have fixed grates exclusively; rocking grates are not used. Some of the railway administrations, however, use drop grates, particularly in the case of larger locomotives, which more especially give good results from the point of view of easier and quicker cleaning of the fire; this is of special importance if the coal contains much ash.

8. Intermediate supports for the boiler. — Some of the railway administrations do not use intermediate supports even in the case of long boilers. On the locomotives of the Austrian State Railway, compensating supports are used; the Austrian Southern Railway uses on all locomotives, except those of small local lines, one to two intermediate supports, according to the length of the boiler; the cylindrical barrel rests on these supports, and when it expands under the influence of heat it can move on the slides or brackets of these intermediate supports. The arrangement on the locomotives of the Aussig-Teplitz Railway is similar; in this case, the intermediate supports also serve as cross bracing for the two frame plates.

9. Shape of front tube-plate. — The locomotives have nearly exclusively front tube-plates placed inside with flange coming forwards, which is riveted to the front ring of the barrel.

The unflanged smoke-boxes coming outside the barrel, used on locomotives of the older type on the Aussig-Teplitz Railway, are at present being replaced by the usual arrangement, as this makes the boiler independent of the frame.

10. Material of tubes. — The tubes are now made exclusively, with very few exceptions, of ingot-iron or mild steel (as a rule seamless; Mannesmann or other similar steel). The fire-box ends of these tubes are protected by rings of copper, or more rarely, of iron.

The use of brass tubes was given up, quite apart from their high cost, chiefly because when lighter fuel (*lignite*) was used, the tubes became worn quickly and irregularly, till they finally collapsed and broke.

The Austrian North Western Railway nevertheless still uses brass tubes in the case of those locomotives which have to use very corrosive water.

The Austrian Northern Railway has quite recently started some trials of mild-steel smoke tubes without copper protection rings; these trials are, however, not yet concluded and results of observations are not yet available.

11. Dimensions of smoke tubes. — The internal diameters of the smoke tubes vary as a rule between 35 and 48 millimetres (between 1 3/8 to 1 7/8 inches), and their thickness between 2·5 and 3 millimetres (between 7/64 and 1/8 inch). As a rule, the diameter is a little reduced at the fire-box ends or a little increased at the smoke-box ends.

The standard smoke tubes of the Austrian State Railway have the following dimensions : 39, 44, 46, 51 and 48, 53 millimetres (1 17/32, 1 3/4, 1 13/16, 2 and 1 7/8, 2 3/32 inches); they are 2·5 millimetres (7/64 inch) thick.

The Hungarian State Railway uses smoke tubes with an internal diameter of 34·5 to 46 millimetres (1 11/32 to 1 13/16 inches) and an external diameter of 40 to 52 millimetres (1 9/16 to 2 1/16 inches); they are 3 millimetres (1/8 inch) thick.

The usual dimensions of the tubes on the Austrian Southern Railway are as follows : external diameter, 53, 51, 50 and 44 millimetres (2 3/32, 2, 1 31/32 and 1 3/4 inches); the first three have a thickness of 2·5 (7/64 inch) and the last one of 2·25 millimetres (3/32 inch). At the ends of the tubes the external diameters are : fire-box end, 47, 46 and 40 millimetres (1 27/32, 1 13/16 and 1 9/16 inches); smoke-box end, 55·5, 53·5, 52·5 and 46 millimetres (2 3/16, 2 7/64, 2 5/64 and 1 13/16 inches).

The smoke tubes with an external diameter of 44 millimetres (1 3/4 inches) are only used on the locomotives of small secondary lines.

The external diameter of the smoke tubes is 50 millimetres (1 31/32 inches), and the internal 45 millimetres (1 25/32 inches), on the Hungarian lines of this railway.

The tubes are made 3·8 millimetres (5/32 inch) larger at the smoke-box ends.

The Austrian North Western Railway uses smoke tubes having an internal diameter of 47 millimetres (1 27/32 inches) and an external one of 52 millimetres (2 1/16 inches); this is reduced to 46 millimetres (1 13/16 inches) at the fire-box ends and enlarged to 53·5 millimetres (2 7/64 inches) at the other ends.

The Aussig-Teplitz adopts a similar practice; it uses smoke tubes of two kinds having diameters of 40/46 and 46/52 millimetres (1 $^{9}/_{16}$/1 $^{13}/_{16}$ and 1 $^{13}/_{16}$/2 $^{1}/_{16}$ inches) respectively. The latter is reduced by 2 millimetres ($^{5}/_{64}$ inch) at the one end and enlarged by 2 millimetres ($^{5}/_{64}$ inch) at the other.

The locomotives of the Bulgarian State Railway have smoke tubes with a diameter of 47/52 millimetres (1 $^{27}/_{32}$/2 $^{1}/_{16}$ inches).

12. Fixing the tubes. — The tubes are fixed in the two tube-plates by means of the well-known roller beader. Tubes with copper rings are flanged at the fire-box tube-plate; ordinary flanging tools are used for the purpose.

13. Serve tubes. — Serve tubes are not used. The Hungarian State Railway had fitted several locomotives with these tubes as an experiment, but no satisfactory results were obtained in practice.

As long as the tubes remained clean, a certain saving in fuel was observed; but in a very short time the spaces between the ribs became clogged. Cleaning them by means of a jet of steam or compressed air gave rise to difficulties and did not suffice, so that any economy is doubtful.

Taking this into consideration, and also the fact that such tubes are difficult to obtain and are expensive, the trials were terminated.

On the Hungarian lines of the Southern Railway, corrugated tubes of the Pogány-Lachmann type are being tried experimentally; these were supplied by the Mannesmann Tube Works.

According to the statement made, a saving of 10 per cent was observed in the case of the locomotives fitted with these tubes; in addition, these locomotives are said to give very few sparks even when light kinds of coal are used and the spark arresters are removed. It is also said that very few cinders collect in the smoke-box. In consequence of the greater elasticity of these tubes, there is less tendency for them to leak.

14. Damage to tubes. — Pitting of ingot iron or mild-steel tubes is observed to a larger extent in the case of locomotives which use water containing salt (chlorides) or carbonic acid. In order to prevent this evil, the Hungarian lines of the Austrian Southern Railway tried tubes made of acid-proof material, but no successful results have as yet been obtained.

The Austrian North Western Railway, with the same object in view, are making trials with the Gölsdorf mud collector; the results are not yet known.

Protective coatings and other means for preventing bad water from corroding tubes have proved unsuccessful, and so have the water purifiers intended to prevent the deposit of scale. The tubes are exposed to the corrosive action of such waters.

The copper ends at the fire-box side become corroded both by mechanical action as well as chemical action, under the heat, particularly at the beads and at the upper

parts of the inside surface, near the opening; this action is particularly marked in the case of forced draft and if the lighter kinds of coal are used. The copper ferrules used as protection prevent, it is true, the beads from becoming burnt, but have the disadvantage of reducing the clear cross-section of the tubes, so that a a greater vacuum is required in the smoke-box, and the hot gases have to enter the tubes at a higher speed. As a result many more particles of fuel, either unburn or partly burnt, are drawn over which in a very short time wear the copper ends to such an extent that collapse and fracture frequently occur.

Wear and fracture of the copper ends immediately at the inner side of the copper tube-plate were not observed; but with the brass tubes formerly used, cracks were sometimes observed near the fire-box tube-plate.

Galvanized tubes are not used.

15*a*. Ferrules for the smoke tubes. — Liners outside the tubes, for keeping the tubes tight, are not used; on the other hand, internal ferrules are sometimes used, particularly in cases where the copper ends are already worn. These ferrules have no taper, and are about 2 millimetres ($^5/_{64}$ inch) thick and 30 to 40 millimetres ($1\ ^3/_{16}$ to $1\ ^9/_{16}$ inches) long.

The drifting in of such rings is injurious, because the seat of the tube becomes conical and damage is easily done to the interspaces of the plate. Although these ferrules protect the beads to some extent against the injurious action of the thin flames, they are but seldom used.

The ends at the fire-box tube-plate are as a rule beaded, and this certainly contributes to the stiffness of the tube-plate. The smoke-box ends are but rarely beaded.

15*b*. Leaking of tubes. — The leaking of tubes is generally caused by: improper firing, working the boiler too hard, consequent sudden cooling of the tube-plate; hard feed-water and consequent deposit of scale on the smoke tubes, immediately at the tube-plate; bad fuel; frequent expanding of the ends, resulting in deforming their circular shape; finally strong wear of the tube, and weakening of the plate in the interspaces. The vibration of very long smoke tubes may also produce leaks.

In order to prevent such leaks, it is advisable to train the locomotive crews to avoid sudden cooling of the tube-plate as much as possible, taking particular care when stopping and standing still after hard work; the ashpan dampers should be closed to prevent the entrance of cold air into the fire-box; cold air is also prevented from striking the tube-plate by the use of arches; hard feed-water should be purified as much as possible in order to prevent the deposit of any large quantities of scale on the tube-plates; tubes with weak and worn ends should be replaced, as they always have a tendency to leak, and frequent expansion into the tube-plate injures the latter. Tubes over 5,000 millimetres (16 ft. 5 in.) in length should be avoided as far as possible, in order to prevent leaks from being started by the oscillation.

16. Arrangement of the tubes. — The tubes are in most cases arranged in vertical rows, but there are a few administrations who arrange them in horizontal rows. The arrangement in vertical rows has the advantage that during the generation of steam the bubbles of steam rise more easily; moreover, if the tubes are arranged in this way it is easier to clean them and remove the scale, and it seems that less scale is deposited in this case than if the tubes are in horizontal rows. Fracture of the tube-plate in the interspaces between the tube holes occurs equally often in both cases, and so does deformation of the holes for the tubes.

The spaces between the tubes vary between 66 and 73 millimetres (between $2\ ^{19}/_{32}$ and $2\ ^{7}/_{8}$ inches), and the thickness of the plates forming the interspaces of the fire-box tube-plate is nearly always 18 to 20 millimetres ($^{11}/_{16}$ to $^{13}/_{16}$ inch). On some locomotives, the distances between the tube centres are within the above limits, but about 1 to 2 millimetres ($^{3}/_{64}$ to $^{5}/_{64}$ inch) less at the fire-box tube-plate than at the smoke-box tube-plate. In many cases, the holes at the top and at the sides of the fire-box tube-plate are made a little smaller, so that the size of the interspaces is increased and fractures occur there more rarely.

17. The use of high pressures. — As a rule, the maximum working pressure is 13 to 13·5 atmospheres. The Hungarian State Railway and the Bulgarian State Railway have locomotives with working pressures of 16 and 15 atmospheres respectively. In order to stiffen the tube-plates, the locomotives of the Hungarian State Railway are fitted with several tubes 8 millimetres ($^{5}/_{16}$ inch) thick; these are screwed into the fire-box tube-plate and beaded, and fixed at the smoke-box tube-plate by nuts inside and out. These tubes have no copper ends at the fire-box tube-plate.

Special measures for keeping the tubes tight are not taken.

18*a*. Measures for preventing cracks in the corners of the tube-plate. — Such measures were not taken. In order to make the copper plate used for the fire box tube-plate stiffer, the plates used for the locomotives of the Hungarian State Railway are hammered cold; but no comparative trials have been made and consequently no final conclusion can be drawn as to the merits of the operation.

In order to prevent cracks in the upper corners of the tube-plate, the two front rows of the stay-bolts are sometimes not extended to the top, but are shorter and fastened to bars supported at one end at the edge of the fire-box tube-plate and at the other by the stay-bolts of the third row of stays.

Stay-bolts with round threads have been tried on locomotives of the Austrian Southern Railway (Hungarian lines) with satisfactory results. Such stay-bolts are said to have less tendency to leak than bolts with angular threads.

18*b*. Repairing fire-box tube-plate. — The repairing of fire-box tube-plates has generally to be effected in consequence of the following defects : tube holes which

are too large or are oval; ridges at the tube holes; cracks in the interspaces; folds, grooves and cracks in the corners of the tube-plate; corrosion at the stay-bolts; bulging and stretching in the vertical and in the horizontal direction.

Large tube holes and ridges, as well as cracks in the interspaces are generally caused by the frequent and too violent expanding and beading of the tube ends.

Large tube holes are either reduced by the introduction of bushes, which are beaded over on both sides, or, if there are also cracks in the interspaces, by screwing in copper plugs, if the plate is thick enough. The same operation is carried out if the diameter of the hole is larger than that of the corresponding tube hole in the smoke-box tube-plate, so that the tube can no longer be taken out without trouble. In order to prevent the tube hole from being drilled out of true, these screwed plugs are provided with a central hole which is then drilled out to the size of the tube end. Any ridges at the tube holes which would interfere must be reduced by hammering.

Oval tube holes occur most frequently near the corners of the tube-plate, and are caused by distortion and by the expansion by heat of the different adjacent parts of the boiler. Such holes are trued by suitable tools (reamers).

If tube holes near the corners of the fire-box tube-plates have become so large, that the beading can no longer be effected owing to the projection of the adjacent rivet heads, they are closed by means of screwed plugs. The screwed plugs used have a slight taper, and have at the large end a strong flat square head; the latter is cut off after the plug has been screwed in. The part left projecting is then used for caulking.

The corresponding tube holes in the smoke-box are closed by bolts and nuts with washers and copper packing rings; this leaves the holes available for future use. Instead of closing the holes in the fire-box tube-plates in this way, some administrations use short pieces of tubes, closed at one end by brazing.

When there are cracks in the interspaces, thick bushes are screwed into the tube holes and beaded on both sides. Some of the administrations cover the cracks in the interspace (a suitable number of tubes being taken out), on the inside by a copper plate about 3 millimetres ($^1/_8$ inch) thick, which is fixed by bushes beaded on both sides. The closing of tube holes, if there are also cracks in the interspaces, by means of screwed copper plugs, as described above, is as a rule only effected when the fire-box tube-plate is to be replaced soon. As a rule, the head of the plug, after it has been screwed in, is drawn over the crack, so that this appears covered over.

Folds, grooves and cracks in the corners of the tube-plate are chiefly caused by the expansion and the contraction of the material in consequence of changes of temperature, and in some cases also by the repeated beading of the tubes. As soon as the folds and grooves become strongly developed, or definite cracks have already resulted, patches are put on (probably only provisionally). The damaged part is cut out, and the patch fitted, and then riveted on, or fixed by screws. If the patch

also extends over any of the rows of tubes, the outer tube holes are closed by screw plugs as described above, and the screws for fixing the patch are driven into these plugs. The intermediate tube holes have bushes put in.

If the tube-plate becomes strongly corroded around the heads of the stay-bolts, either stay-bolts with larger heads are used or bushes are put into the stay-bolt holes. Bulges on the tube-plate, if not too large (say 20 millimetres [$^{13}/_{16}$ inch] as maximum) are again pressed in, if the tube-plate is otherwise in good condition and there are few or no cracks in the interspaces. In order to carry out this work, a sufficiently strong plate is applied on the inner side, so that this takes at the top against the corner of the tube-plate and at the bottom against the tube-plate stay-bolts. This plate has a number of holes and through them and the corresponding tube holes bolts are passed, with large washers on the ouside. The nuts are then carefully and gradually tightened up in succession, until the plate has been restored to its original shape.

It is becoming rarer and rarer to repair the tube-plate as well as the other walls of the fire-box by means of patches, owing to the continual increase in their dimensions and in the pressure of the steam; and the life of the fire-boxes of the newer types of locomotives is accordingly materially shorter than with the older types.

19. Extended smoke-boxes. — These are only used by a few railway administrations.

The Austrian State Railway has smoke-boxes of medium length. The Austrian Southern Railway has smoke-boxes with a length of 1·2 to 1·6 metres (3 ft. 11 $^1/_4$ in. to 5 ft. 3 in.); it also, as an experiment, has a number of locomotives with smoke-boxes 1 6 to 1·7 metres (5 ft. 3 in. to 5 ft. 7 in.) long. The administration in question has not found that the latter present any decided advantage.

The Austrian North Western Railway also has locomotives with extended smoke-boxes, but these have not satisfied expectations.

The Aussig-Teplitz Railway uses extended smoke-boxes on its newer locomotives; it mentions as an advantage of this type that there is more room for the flue dust to settle, and this is important when the fuel used is lignite.

The Hungarian State Railway build all their locomotives with extended smoke-boxes, in consequence of extensive trials which were made with various kinds of spark arresters. These trials showed, particularly when lignite was used, that sparks were fewest in the case of extended (American) smoke-boxes, while the steam production was not hindered by any reduction of the draft or by greater cooling of the smoke-box tube plate. These smoke-boxes also have the advantage, that they become heated less, and consequently there is less tendency to deformation and leakiness; moreover there is plenty of room for flue dust and consequently the lower rows of tubes do not become obstructed so soon.

20. Steam dome. — All the locomotive have steam domes, which are made as large as possible so as to have as dry steam as possible. A few of the locomotives

of the Austrian State Railway, of the Austrian Southern Railway, and of the Hungarian State Railway have two domes, which are connected by a tube placed outside.

The Hungarian State Railway have some types of locomotives fitted with sheet iron in the steam dome, to separate the water (steam drier); this has proved satisfactory.

Steam driers of the Clench type are used by the Austrian State Railway; the Austrian Southern Railway and the Hungarian State Railway are trying the Gölsdorf steam drier.

21. Heat insulation. Lagging. — As a rule only sheet iron is used as lagging for the locomotive boilers. The Austrian State Railway and the Austrian North Western Railway have recently however also used asbestos lagging, but have not made any comparative trials. The Austrian Southern Railway and the Aussig-Teplitz Railway cover only the fire-box shell with asbestos cloth, to protect the locomotive crews; in this case also, no comparative trials have been made to determine its efficiency.

The Hungarian State Railway made comparative trials of boilers covered with sheet iron and with asbestos years ago, and it was found that with asbestos lagging there was some economy of fuel. But subsequent experience showed that this comparatively-small saving is at least counterbalanced by extra cost of acquiring and maintaining the asbestos lagging. It is intended to make new trials, especially of asbestos lagging for the fire-box shell, and to observe its efficiency as regards the protection of the locomotive crews.

22. Thermal storage. — No arrangements for thermal storage are used, except refractory arches in the fire-boxes of locomotives of several railway administrations; it has been observed that their use results in a fuel economy of 4 to 5 per cent.

Conclusions on Subject VI, littera A.

The design of the smoke-tube boilers of locomitives, now in use for a long time, is still as a rule based on the following principles.

The fire-box shells are made round topped; the inner fire-boxes are made of copper; stay-bolts are generally used for the connexion. Sometimes the fire-boxes are made wide, *i. e.* projecting beyond the frame plates.

The locomotives have level grates; drop grates are used in some cases and not in others.

The smoke-tubes are made of ingot iron or mild steel; brass tubes are only used as an exception. Apart from a few solitary experiments, only smooth tubes are used.

Copper ends are generally brazed to the iron tubes at the fire-box side. The tubes are in most cases arranged in vertical rows.

The working pressure of the more recent locomotives varies between 13 and 16 atmospheres.

No special measures, apart from those generally known, are taken to prevent any damage to the boilers; the same applies to the repair of boilers.

With the more recent locomotives extended smoke-boxes are used in the majority of cases.

The heat insulation of the boiler consists chiefly of sheet iron, with a non-conducting layer of air in between. Asbestos lagging is only used in a few cases.

Refractory arches are often used in the fire-boxes.

LITTERA *C*.

Damage to Boilers. Purification of water. Disincrustants.

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1. Processes for softening water. — The purification or rather the softening of the feed water is as a rule effected by the addition of soda, or if required, of lime. These substances are added, in the proportions prescribed, either in the boiler or tender, or else there are special apparatus provided for purifying the water. The purification is seldom effected in the water tanks of the water-supply station, because although this is probably an inexpensive proceeding, the pipes become blocked up easily.

The control of the proper purification consists chiefly in making frequent analyses of the purified water and also in the careful supervision of the apparatus used.

On the Austrian State Railway, the feed water is softened by the Breda, Dervaux-Reisert, Desrumeaux, Kenikott and Wehrenpfennig methods; lime and soda are added in all cases. In some cases the lime-baryta system (quick lime and barium carbonate) is also applied. In order to ensure proper working the apparatus is inspected from time to time by experts, and analyses are made both of the original and of the purified water. Comparative trials are now being made with apparatus of the above systems in order to determine the action, the cost of installation and the cost of operation of the different systems. Particulars on the subject are given in an article in the *Zeitschrift des österreichischen Ingenieur und Architekten Vereins*, 1908, No. 46.

No water-purifying apparatus are at present in use on the lines of the Austrian Southern Railway, for supplies of good water have been laid on and make purification unnecessary. Formerly Beranger, Stingl and Wehrenpfennig apparatus were in use.

The Austrian North Western Railway has installations for the lime-soda process

at six water-supply stations. The trained water men have to examine the original and the purified water and the liquid reagents added, by volumetric methods.

The Bulgarian State Railway proposes shortly to introduce the " Voran " process of the " Frankfurt Apparatbau-Gesellschaft ".

On the lines of the Hungarian State Railway fixed installations for purifying water only exist or existed at a few stations, the systems tried being the Stingl-Beranger, the Pollatschek, the Gaillet and the Derveaux-Reisert; but as a rule only soda is used, which is added, without any special apparatus, direct to the boiler or tender water, in the proportion specified by the chemical laboratory. In the case of the small automotor boilers, the feed water is purified in a separate tank by means of soda and lime. In one case, the strongly-alkaline water is purified by the Adorján-Pfeifer process, lime and gypsum being added.

The control is effected by occasionally making analyses of the original and of the purified water.

It is also noted that no satisfactory results are obtained if attempts are made to purify water containing sodium chloride or water contaminated by the drainage from manufactories. At such places, new wells are sunk or water is brought from a distance in order to obtain a supply of good feed water.

The need for water purification is every year becoming less and less on the lines named, for care is taken, in succession, that all the water-supply stations have a supply of good feed water, either laid on from a distance or obtained by sinking deep wells.

2. Results of the water purification. — It is generally recognized that it is advantageous to purify the boiler feed water; but no administration is in a position to give any figures as to the economy realized.

According to the information supplied by the Austrian State Railway, its numerous water-purifying installations have been in use too short a time to make it possible to draw any definite conclusions from the results hitherto obtained, about the different systems as compared with each other, as well as about the cost of working them.

The cost of maintenance of the boiler barrel is very low, and this barrel has such a long life, that boiler plates even thirty years old are to be found, which are then replaced in the interests of safety. The cost of maintenance of the fire-boxes, particularly of the copper fire-boxes is very great, and their life is short. They can seldom be used for more than ten years, and in many cases fire-boxes have already to be renewed in five and even in three years.

Exact figures as to the cost of repairs to the boilers cannot be given; this depends on the size and design of the boiler, and on the quality of the material of which it is made; it varies between 1,100 and 9,500 kronen (between £46 and £396) per boiler per five years.

On the locomotives of the Hungarian State Railway, the condition of the boilers

has decidedly improved since the feed water has been properly purified. The life of a locomotive boiler is on the average eighteen years.

3. Softening of water containing calcium and magnesium sulphates, chlorides and nitrates. Preventon of priming. — Feed-water of this composition is exclusively softened by the use of soda, and priming is prevented by taking care that no excess of soda is added. Care must also be taken to wash the boiler out frequently; in some cases the boiler is also blown off at a low pressure.

The Austrian State Railway softens water of this kind by adding only so much soda that the total alkalinity of the purified water is half its hardness.

According to the experience of the Austrian Southern Railway, softening the water by means of soda and lime has not given satisfactory results, because this prevents the formation of scale which protects the boiler against corrosion, and the chlorides, which are not removed by the softening process, can then attack the exposed surfaces of the boiler and of the tubes.

It has accordingly proved more satisfactory, in such cases, not to treat the water, but to clean the boiler and the tubes frequently.

Some of the administrations do not purify such waters at all, and try, as far as possible, to avoid their use.

4. The use of barium compounds. — Only at one water-purifying installation on the Austrian State Railway is barium carbonate used for softening water containing sulphates; and very good results are obtained. The advantage of this process consists in the absence of any subsequent reaction, so that the supply pipes remain free from incrustation. It is also possible, in the case of this process, to soften the water very thoroughly, as the purified water contains no salts in solution (sodium salts, magnesium sulphate).

5. Determination of the quantiy oe sodium salts in tae water of locomotive boilers when priming commences. — No data are available on this subject; it was however observed on locomotives of the Hungarian State Railway that in the case of boilers which have an old deposit of scale, the sodium salts only remain dissolved in the water to a very limited extent, namely 0·05 to 0·1 kilogram of sodium carbonate per cubic metre (0·0031 to 0·0062 lb. per cubic foot) of water.

6. Means for preventing the formation of scale. — The different nostrums, some of them secret, which are sold under various names, for preventing the formation of scale, or at least of hard scale, in the boiler, consist chiefly of impure soda, organic substances containing tannic acid, and sometimes of cellulose or other insoluble substances. These universal nostrums are as a rule of very minor importance; they are expensive and the same result, namely a muddy deposit instead of a coherent scale, can be attained much more cheaply by adding a corresponding quantity of pure soda to the water in the boiler or in the tender.

Such nostrums have been repeatedly tried on the Austrian Southern Railway, as well as on some of the locomotives of the Hungarian State Railway, but always without particular success. The results are always unfavourable from the economic point of view. These nostrums must also be looked upon with suspicion as regards the possibity of promoting ultimate corrosion.

The Aussig-Teplitz Railway uses the oil which is used for lubricating the cylinders, for preventing the formation of hard scale. The day before the boiler is washed about 0·5 kilogram (1·10 lb.) of oil is injected into the boiler; the oil loosens the scale from the walls of the boiler.

7. Influence of the disincrustants on the smoke tubes, stay-bolts and boiler seams. — The use of the different disincrustants was not observed to result in greater leakage of tubes or stays, nor have they caused any other damage to the boilers.

8. Defects in the boilers. — The defects which are produced in the boilers cannot strictly speaking be considered separately, as they partly are interdependent. They can be divided into two chief groups : those which as experience shows always arise in the same way and usually at the same points, and those which turn up unexpectedly and in single instances.

The first group includes those defects, whose origin is to be sought in the mechanical action of the heat or in the chemical aétion of the water and the fire, that is of the fuel. The expansion of the different constituent parts of the boiler, in spite of the different devices which are intended to make free expansion possible, can always take place without hindrance. In consequence of the design, there will be considerable resistance at some points and injurious strains will result; these in course of time will produce folds and grooves, and finally cracks. Experience has also shown that it is just at those points, which are subjected by the mechanical action to other stresses than the adjoining parts, that chemical action becomes particularly marked and produces corrosion. The points in the inside of the boiler, named below, are those at which both actions occur and consequently defects appear most quickly. Folds and grooves are found and if these are not attended to in good time they become cracks; these are formed : in the corners of the fire-box plates and of the outer shell, at the throat plate at the junction of the barrel and the fire-box, at the side walls above the last ring and at the top of the upper row of stay-bolts, at the transition from the flat to the curved parts.

Corrosion is most marked : at the bottom plates of the barrel, where the corrosion is generally greatest at the lowest points and decreases upwards; near the caulked edges of the plates, parallel to them and also decreasing with the height; at the front bottom plate, close to the smoke-box; also in the corners in the smoke-box tube-plate.

Funnel-shaped corrosions are found round the washing-out plugs, and also

round the stay-bolts at the inner side of the fire-box wall. Also at the iron stay-bolts and stays, at the rivet heads, at the last ring, particularly at its outer side, at the fire-door frame, at the edging of the washing-out holes. Finally at those points which owing to their position are difficult to clean.

Thus corrosion can arise at many points, and there is scarcely any part of the boiler which is not liable to it. But when it is known here it appears, appropriate measures can be taken before the magnitude and amount of the corrosion has reduced the strength of the material to such an extent that cracks begin to be formed and that there is risk of explosion.

Bulges occur chiefly in the copper fire-box plates, between the stay-bolts. They are caused by the reduced resistance of the copper in consequence of local overheating, probably chiefly produced by the formation of large quantities of scale inside the boiler.

The second group of defects which appear suddenly and unexpectedly, are mostly the result of material of bad quality and of bad workmanship. They generally consist of cracks which appear spontaneously in the plates, namely cracks at the rivet holes. These are caused either by the bad quality of the material, or by bad workmanship; for instance if two rivet holes which do not come exactly over each other or are too small, are drifted too strongly. The direction of the cracks is either radial, or parallel to the edge from one to the other, or at right angles to the edge.

Cracks in the barrel along the caulked edges. They are caused either by the plates having been bent at too low a temperature or by too sharp bends. Longitudinal cracks at the sides, above the boiler supports, are caused by want of proper support. Too forcible caulking can also produce cracks along the caulked joints comparatively easily, as the ingot-iron plate used is rather sensitive.

Such cracks were often observed at points where other causes could be suspected.

The fracture of roof stay-bolts and of tube-plate stays is to be explained by the use of material which is not tough enough, and so is also the fracture of angle and plate stiffening. The appearance of unexpected cracks often also depends on the design of the boiler and on the way it is treated and worked. Sudden great demands followed by a quick drop of temperature are exceedingly injurious. Finally it may be remarked that it is very possible, by careful inspection, to detect some cracks, when they begin to be formed, and further evil consequences can then be averted.

As regards the formation of rust inside boilers, a series of articles on the subject appeared in the *Organ für die Fortschritte des Eisenbahnwesens*, 1891 and 1892.

After these general remarks we will now classify the observed defects into four groups and give particulars about them below.

1° *Cracks and fractures.* — Cracks and fractures occur principally in the corners of the fire-box tube-plate, the fire-hole ring and the throat plate; also in the inter-

spaces of the tube-plates, and at the edges of the plates, extending there from the rivet holes and the stay holes. Cracks, as long as they are not dangerous, are drilled out and screwed plugs are inserted.

2° *Pitting and honeycombing.* — Pitting, in various forms, is found inside the boilers chiefly in the lower portions of the barrel at the bottom; more rarely in the steam space of the boiler, and along the rivets and joints of the fire-box. These phenomena appear, when the metal used is not homogeneous, at the points where different metals are in contact; they are also promoted by quick and frequent variations in the temperature, and by the influence of certain kinds of feed water.

External corrosion at the lower parts of the fire-box plates is chiefly caused by the use of fuel containing sulphur.

3° *Grooving.* — Grooves are found more especially at the corners of the fire-box plates; when the plates are bent, a number of minute sharp-edged cracks are formed, which are widened and deepened by the effect of the fire. Similar grooves are also formed on the water side of the fire-box, at the corners of the shells and the throat plate.

Vertical grooves are also often formed along the stay-bolt rows.

4° *General surface corrosion.* — This is chiefly found along the bottom of the barrel, at the corners of the fire-box plates and along the fire-box plates in a vertical direction between the stay-bolts, or in a horizontal direction in the lower parts; also at the bottom of the smoke-box and around the washing-out plugs.

Corrosion caused by the fire is often found at the tube-plate and the other fire-box plates; these are caused chiefly by forced draft or by the action of fuel containing sulphur.

9. Notes and sketches of the condition of the boiler. — Records are generally kept about the boilers undergoing repair, and their defects, and in some cases sketches are made. The corresponding procedure adopted by the different railway administrations is as follows :

The Austrian State Railway prescribes that a report is drawn up each time a boiler is repaired; particulars must be given of the state of the boiler before it was repaired, and details of the repairs carried out. A book is kept for each boiler, in which all defects and their removal are described from the time the boiler was built till it is finally condemned. In special cases, accurate dimensioned sketches are made of any extensive corrosion, and plaster casts are sometimes also made. Detailed particulars on the subject, as well as a description of the records and notes usual on the Austrian State Railway are given in the work *Handbuch des Eisenbahn-Maschinenwesens*, by von Stockert, 1908 edition, volume III, page 197.

The repairs to locomotive boilers on the Austrian Southern Railway are entered, in each case, in a report, sent to the administration, where all these repairs are duly recorded. Sketches or plaster casts of any defects existing in the boilers are

only made in exceptional cases, in order to decide what repairs are to be undertaken, or to make it possible to see how the defects in question progress subsequently.

Fractures, cracks, corrosion, etc., when the boilers on the Hungarian lines of this railway undergo heavy repairs, are sketched and recorded on repair sheets. The Austrian North Western Railway draws up reports about the internal and external examination of the boilers, and if necessary, sketches are added.

On the Aussig-Teplitz Railway notes and sketches of boiler defects are only made for the use of the workshop which are going to do the repairs. In addition, reports as to the inside state of the boilers are submitted every year to the supervising authorities.

The Hungarian State Railway also draws up a report when a boiler is examined; this is entered in the corresponding locomotive stock books. Sketches are made of large defects in the boilers.

10. Modifications in the design of locomotives to prevent the defects observed. Breadth of waterspace in the fire-box. Delivery of feed water. — There is no general tendency towards modifying the design of locomotive boilers in order to prevent the defects observed; only in a few cases are a few details altered. It may be considered a generally-accepted principle that the fire-box corners should be bent to as large a radius as possible in order to prevent the formation of grooves and of folds. Several administrations, in order to prevent corrosion at the bottom of the barrel and also at the lower inner edge of the fire-box, use thin plate riveted direct to the frame, about 5 millimetres ($^3/_{16}$ inch) thick, made of steel in the barrel and of copper in the fire-box. These protective plates have given good results, but their use was given up in the case of the locomotives of the Hungarian State Railway, because to remove them when the boiler was examined was a matter of difficulty, and to put in fresh plates was impossible. The Aussig-Teplitz Railway also used protective plates made of copper for the bottom plates of the barrel; these however gave unsatisfactory results and were again removed.

Other details for preventing defects in boilers are wider spacing of the stay-bolts, cylindrical fire-box tops and finally Gölsdorf mud separators, such as are used on the Austrian North Western Railway and which are expected to reduce corrosion.

At present many hold the opinion that the increasing defects which are caused by the continual increase in the working pressure, particularly at the fire-box by the high temperatures, can at least in part be avoided by the use of superheated-steam locomotives, and that the maintenance of boilers will then give more favourable results.

The water space in the fire-box walls is about 60 to 80 millimetres ($2\ ^3/_8$ to $3\ ^5/_{32}$ inches) wide at the bottom and 100 to 150 millimetres (4 to 6 inches) at the top. On some of the new locomotives this dimension is increased to 180 millimetres ($7\ ^1/_{16}$ inches). The official regulations prescribe that the water level must be at least 100 millimetres (4 inches) above the top of the fire-box.

The feed water is delivered into the boilers of most locomotives at the centre line either at the middle of the barrel or in the front third; in many cases, straight under the steam dome. At the point of delivery there is generally both a check and a stop valve. The Austrian North Western Railway has locomotives with the feed water introduced at the bottom of the barrel. This administration, as already stated, is also making trials with the Gölsdorf mud collector; the feed water is led through this apparatus to the boiler. Attempts to introduce the feed water into the boilers through the smoke-box tube-plate and trials with feed water heaters are at present being made on the Hungarian lines of the Austrian Southern Railway.

Injectors are used generally for feeding the boilers, the non-lifting kind being chiefly used.

The Hungarian State Railway is at present trying two kinds of feed-water heaters. One of these is the Brazdá type, in which the feed-water is heated in a special tank by means of live steam, and then after it has become sufficiently heated and the pressure has become equalized it is admitted direct into the boiler. This has the advantage that the whole of the scale is formed in the feed-water heater, and is only deposited in the locomotive boiler in the form of fine mud, no hard scale being formed.

The other with which trials are at present being made is the Caille-Potonier apparatus, in which part of the steam from the exhaust is used for heating the feed-water. The water which is heated to 90° C. (194° Fahr.) or more is then delivered to the boiler by a special pump.

Neither of these apparatus has yet been fully tested, so that no final opinion can be expressed as to their value.

11. Washing out locomotive boilers. — The locomotive boilers of the Austrian State Railway are washed out either with cold or with hot water, according to the appliances available at the locomotive depots; but it is desired to introduce the latter system generally. The time between two washings out varies between five and twenty days, according to the quality of the feed-water. If the boiler is washed out with cold water, the time allowed before the water is drawn off is up to twelve hours, according to the size of the boiler, and another two to four hours are allowed for the cooling of the empty boilers, so that about sixteen hours are spent altogether. The pressure used depends on the dimensions of the boiler and the number and distribution of the washing-out holes, and varies between 1 and 8 atmospheres. If hot water is used, the water required is either provided by operating the apparatus by another locomotive, which is in steam, or else the Wittenberg and Schildhan system is in use. In this case, the steam still left in the boiler which is to be washed out, after the locomotive has stopped, is used to heat the water in the tender; a portable centrifugal or other pump, driven by an electric or a benzine motor then supplies this water for washing out the empty boiler which is cooled to a corresponding extent.

On the lines of the Austrian Southern Railway, locomotives are at present still washed out with cold water in most cases. At some depots however, there are already installations on the Wittenberg-Schildhan system, using water heated to 70 or 80° C. (158 or 176° Fahr.). When this system is used, the total time required from the time the locomotive stops running till it is ready again, can be reduced to six hours.

The time between two successive washings out varies, according to the quality of the water used, between six and ten days; *i. e.* about 1,000 to 2,000 kilometres (620 to 1,240 miles) are run in between. The pressure of water used for washing out is in most cases 1·5 to 3 atmospheres, according to the height of the tanks; but there are also cases where the pressure amounts to 5 atmospheres or even more.

On the Hungarian lines of this railway, the locomotive boilers are washed out exclusively with hot water, according to the Wittenberg-Schildhan system, after every 700 to 1,000 kilometres (435 to 620 miles), without taking any account of the quality of the feed-water. The pressure of the water used for washing out is 2 to 4 atmospheres.

The locomotive boilers of the Austrian North Western Railway are in part washed out with hot water. The average distance run between two successive washings out varies between 220 and 1,500 kilometres (between 136 and 930 miles). The quality of the feed-water is taken into account in fixing these distances.

Eight to ten hours are allowed for cooling before washing out with cold water. The pressure used in the case of cold water is 0·5 atmosphere, and in that of hot water is about 2 atmospheres. In the latter case, the hot water is obtained from the injector of another locomotive which is in steam, and the overflow valve is taken off, the washing-out hose being coupled on instead.

The boilers of the Aussig-Teplitz Railway are washed out similarly, some with hot water and some with cold, according to the number of locomotives in steam which are available, as a locomotive in steam is required for each locomotive which is to be washed out hot. The time between two washings out varies from seven to nine days.

When cold water is used for washing out, four hours are allowed for the previous cooling of the boiler.

The pressure of water used is 1 atmosphere in the case of cold water and 3 to 4 atmospheres in that of hot. The process when hot water is used is as follows: a locomotive in steam stands on a parallel track next to the locomotive which is to be washed out. The overflow of the injector of the locomotive in steam is joined by a metal coupling to a hose which is also used for washing cold. One man manipulates the nozzle of the hose, while a second man attends to the injector. The pressure of steam must not exceed 6 atmospheres. The washing can be started as soon as the water has been let out of the boiler. After the washing out is completed, the boiler is filled with warm water by the same injector which was used for the washing out.

The locomotive boilers of the Bulgarian State Railway are as a rule washed out with hot water, after every 1,200 kilometres (745 miles) run, on the average. At least one hour is allowed to elapse after the locomotive has stopped, before the steam is blown off. Then the boiler is allowed to cool off for eight or ten hours. The hot water used for washing out has a pressure of 5 to 6 atmospheres.

The locomotive boilers of the Hungarian State Railway were until now chiefly washed out with cold water, or with hot water supplied by the injectors of locomotives in steam, in the same way as described above. Washing out with hot water is however becoming more and more usual, and besides the method described above (using the injector of a second locomotive which is in steam) the following systems are either in use already or are going to be used :

1° Portable powerful injectors which are supplied with steam either from a locomotive or from a stationary boiler put up for the purpose. Preliminary trials were successful and it is accordingly intended to lay steam pipes at the locomotive depots in question so that the washing out can be effected at any convenient place;

2° Hot-water tanks with the necessary piping. The water in the tank is heated by sending in the steam from locomotives which have come in or from a boiler put up for the purpose. As yet none of these installations are in existence, but a start will shortly be made with them;

3° The Wittenberg-Schildhan system of washing out with hot water, as already described above.

The newer methods for washing out boilers which have been described are however still in the experimental stage and it is hence not yet possible to decide which of them is best from the points of view of utility, of the requirements of the traffic, and of economy. The experiments are, however, going to be continued on a larger scale.

The locomotive boilers are washed out on the average after every 600 to 700 kilometres (370 to 435 miles) run; but this distance is increased to 1,000 kilometres (620 miles) in the case of good water, but reduced to 350 or 480 kilometres (217 or 300 miles) if the feed-water is very bad.

The locomotive with the Brazda feed-water heater is only washed out after it has run 6,000 to 8,000 kilometres (3,700 to 5,000 miles). Distances of even 10,000 kilometres (6,200 miles) have been run between two successive washings out, without finding any hard adherent scale in the boiler; a good deal of mud was alone deposited in the lower parts of the boiler, and this could easily be washed out. At intermediate times some of the boiler water is allowed to run out, at reduced pressure, and this at the same time removes part of the deposited mud. This trial is also not concluded yet.

When cold water is used for washing out, the boiler, after blowing off the steam,

is allowed to cool for at least six hours (eight hours in the cold seasons) before the washing can be begun. In urgent cases the following procedure is adopted : after the locomotive has been taken to the depot, it is filled with water and then allowed to stand in this condition for three or four hours. Then the lower blow-off cock at the fire-box is opened to a moderate extent, and the water allowed to run off slowly, but at the same time the same quantity of cold water is admitted at the top, so that the level of the water remains unaltered. After the boiler is cooled, the water is then allowed to run off altogether, and the washing out is then effected in the usual way. The chief advantage of this method, it is stated, is that the scale adhering to the inside of the boiler and to the tubes does not become dried on, and is hence easier to remove.

The pressure of the jet of water used for washing out is as a rule 0·5 to 1·5 atmospheres: but it is higher with the newer installations and in some special cases attains 4 atmospheres as a limit. The latter pressure is also attained when hot water is used for washing out.

12. Blowing off and emptying the boiler. — Blowing off the boiler, when it is in steam, in order partly to empty it and to remove the mud, is a proceeding only adopted by a few railway administrations. On the Austrian State Railway, the water in the boiler is run out at a pressure of about 0·5 atmosphere, when the boiler is to be washed out. The Austrian Southern Railway uses a pressure of 1 to 1·5 atmospheres for this purpose; in some cases, part of the water is allowed to run off at shorter intervals, in order to remove mud or to prevent too great a concentration of any injurious substances in the water. On the lines of the Hungarian State Railway, blowing off the boiler, that is to say, blowing off part of the water, is a proceeding carried out at some of the locomotive depots, chiefly when muddy or very alkaline feed-water is used, partly in order to get rid of the mud, partly in order to prevent priming; but this is not an economic method. It is certainly better, if enough time is available, to run off all the water and wash out the boiler with hot water.

Some railway administrations on principle only allow the water to run out when there is no longer any pressure in the boiler.

The blowing-off of the boiler, as well as the removal of the water is practically always effected by means of blowoff cocks which are fitted, low down, to the front plate of the fire-box, and which in many cases are operated by means of a long key from outside the frame plates. Some locomotives have such cocks also at the bottom of the barrel.

13. Waters specially corrosive to boilers. — The only railway that mentions any such water is the Austrian North Western Railway. This administration gives the following analysis of a water, which is purified by means of lime and soda, and

which in all probability attacks all the iron parts of the boilers in which it is used :

Lime Ca O	14·94	parts	per	100,000.
Magnesia Mg O	11·02	—	—	—
Potash K_2 O	22·73	—	—	—
Soda Na_2 O	6·68	—	—	—
Sulphuric acid SO_3	38·30	—	—	—
Chloride Cl	3·75	—	—	—
Carbonic acid CO_2	15·72	—	—	—
Silica Si O_2	1·72	—	—	—
Ammonia NH_4	1·72	—	—	—
Total solid residue	120·08	—	—	—
Ditto after ignition	113·22	—	—	—

14. Protective coatings and special treatment of the water in order to prevent corrosion of the boiler. — The Austrian North Western Railway uses saturated lime water the first time the boiler is filled and tested, so that any acid which may be present at any of the seams, etc., may be neutralized. Experiments with any coatings have only been made on a small scale, and no opinion can be given as to the merit of any such coatings.

The Bulgarian State Railway, as soon as any corrosion is observed in the boiler, applies a protective coating of petroleum or of tar.

The Hungarian State Railway has tried to protect the inner surfaces of the smoke-box against corrosion, by a coating of cement; but this was given up as no particular advantage as regards the preservation of the plate could be observed.

Other protective measures are not used anywhere, unless we include under this head the protective plates already mentioned under question 10.

15. The use of zinc plates in boilers. — The use of zinc plates in boilers in order to prevent the formation of scale and the corrosion of the boilers, is not practised anywhere.

16. Metal used for stay-bolts. Their fracture and other defects. — The Austrian State Railway uses copper as a general rule for stay-bolts; in the case of ingot-iron fire-boxes however, ingot-iron stay-bolts are also used. Stay-bolts of manganese bronze are being tried; as far as present results go, this metal is only suitable for stay-bolts which are subjected to the very great tensile stresses. In the case of stay-bolts subjected to smaller stresses, it is preferable to use copper, which is more easy to work and get tight. Records on this point are not kept.

Holes are drilled through the stay-bolts; flexible stays are not used.

It is forbidden to use electrolytic copper for stay-bolts, unless it has gone through some casting process.

On the Austrian Southern Railway only stay-bolts made of copper or iron are used; manganese bronze and other alloys have only been used experimentally, and

no particular advantage resulted. Copper stay-bolts are exclusively used on the newer locomotives; on the older locomotives the five lower rows and the stay-bolts in the upper corners of the fire-box are made of copper, and the others of iron.

The stay-bolts break as a rule at the threads inside the fire-box plates, and the corner stay-bolts mentioned above are particularly liable to fracture because there the differences between the expansions of the inner and the outer plates are greatest. In order to enable these fractures to be detected at once, holes are drilled into the stay-bolts from the external end to a depth of about 25 millimetres (1 inch); the diameter of the hole is 5 millimetres ($^3/_{16}$ inch). Stay-bolts made of copper rod with a small hole right through have recently been tried as an experiment. Flexible stay-bolts are not used.

On the Hungarian lines of the Southern Railway, experiments have also been made with manganese-bronze stay-bolts. The working of this hard alloy takes much time. These stay-bolts have given good results as far as the upper rows are concerned; it is however stated that the heads of the stay-bolts at some places easily crack off.

The Austrian North Western Railway also uses copper and iron as material for stay-bolts. Valuable information about the fracture of stay-bolts and their examination is to be found in the work *Défauts des chaudières des locomotives et des locomobiles*, translated from the German by Eduard Franken, Paris, Librairie Polytechnique, Baitry et C^ie^, 1895.

Flexible stay-bolts are always used in the first row of the roof stays. It often happens that the head of a stay comes off.

The Aussig-Teplitz Railway uses copper stay-bolts exclusively. Fractures occur at any part of the fire-box, but chiefly at the middle of the sides, on the outer shell.

Holes are drilled into both ends of the stays, and all the stays, without exception, are rigid. The heads are sometimes burnt away, but it has never been observed that they crack off.

The Bulgarian State Railway also uses only copper as material for stay-bolts. Any fractures which occur are nearly always close to the plates, and chiefly at those parts of the sides of the fire-box where the greatest movement is produced, partly by the pressure of the steam and partly by local overheating; also at those places where the expansion of the fire-box walls is considerable; and finally also at those places where the stay-bolts become corroded by bad feed-water.

The Hungarian State Railway uses stay-bolts made of pure copper, and more recently of phosphor bronze (copper with 13·99 per cent of phosphorus). Formerly, manganese bronze stay-bolts (4 per cent of manganese) were also used; but the hardness of this material not only made it difficult to make the stay-bolts, but also made it difficult to shape the heads and get them tight. For this reason, and also because leaks frequently started, manganese bronze is no longer used.

Fractures of the stay-bolts most frequently occur in the top horizontal and in the outside vertical rows, and the sides at these points then begin to bulge. The frac-

ture is usually immediately at the inner side of the fire-box plates. In order to facilitate the detection of such fractures, a hole is drilled through the whole length of the stay-bolt and this hole is rivetted up on the outer side. Issuing steam then shows if a stay-bolt is broken, and a new one is at once put in; the immediate renewal is particularly important if the fracture is in the top or the outer rows of stay-bolts.

Flexible stay-bolts were also tried as an experiment, but it was found that they soon became coated with scale to such an extent that they lost all their flexibility and consequently no longer acted.

The stay heads, particularly if forced draft is used, quickly burn away, particularly under the fire arch, and then crack off when tightened.

17. Refractory linings for fire-boxes. — The Austrian State Railway has tried such linings, but without success.

The Austrian Southern Railway does not use such protective linings. On most of its locomotives however, there are fire arches made of refractory brick in order to deflect the flames and also to improve the combustion and utilize the heat better. Such arches, which are really not protective devices, are also used with success by other railway administrations.

The Austrian North Western Railway has made trials in the way of lining the lower parts of the fire-box sides with a mixture of kaolin, fire-clay, graphite and asbestos in different proportions (the Spiegelhalter patent, Miskolcz, Hungary), but with unsatisfactory results, as the lining soon came off.

The Hungarian State Railway has made extensive trials with the Spiegelhalter protective lining; this consist of a mass which is cemented on to wire netting which is secured to some of the stay-bolts by means of pins, at the lower parts of the fire-box walls, and extending up to a little beyond the fire. It was found that when coal containing much sulphur, but not of the caking kind, was used, the protective lining continued to adhere fairly well, and the covered parts of the fire-box walls remained undamaged, while the steam production was not affected unfavourably. With caking coal, or with coal containing much slag, this slag became largely deposited on the protective lining. As a consequence, this lining, which originally was about 5 centimetres (2 inches) thick, became much thicker and interfered with the fire, and consequently had a bad effect on the steam production. A good deal of force is required to remove this accumulated slag, and this damages the lining and separates it from the walls. Much repair is consequently necessary, resulting in loss of time and in expense. It was moreover observed that with certain types of locomotives, when the protective lining in question was used, leaks at the tubes occurred with remarkable frequency; it has not yet been definitely ascertained what this is due to.

The experiments with the Spiegelhalter protective lining are not yet concluded, and its economic effect has not yet been determined.

Conclusions Subject VI, littera C.

The observed defects in locomotive boilers occur typically on all railways in practically the same generally known way. Special phenomena of this, in the case of individual boiler designs, were not reported and do not appear to have been observed. Special means for preventing defect in boilers do not exist.

The feed-water is purified either in the boiler and in the tender, more rarely in the water-towers, or in special water-purifying installations, of which there are however but few. No data are available as to the influence of the different purifying processes on the maintenance of the boilers and on the economic results.

The chief disincrustants are soda and lime. So-called anti-fouling compounds are as a rule not used.

The boilers are washed out both with cold and with hot water; there is a tendency to extend the latter system and in some cases special installations are provided for the purpose.

Apparatus for heating the feed-water, and for separating the boiler scale, are being used experimentally.

As material for stay-bolts copper is chiefly used; manganese bronze only to a very limited extent.

Protective linings for the fire-box walls are only in use experimentally.

APPENDIX.

Detailed list of questions relating to question VI.

LITTERAS *A* AND *C*.

LITTERA A.

1. What type of boiler do you use? Belpaire or round- topped? Please forward drawings of your latest standard types.

2. If you use round-topped boilers, do you use roof- bar or radial stays on the firebox crown sheets? Kindly state what special advantages you find from each type.

3. Have you any locomotives fitted with cylindrical fire-boxes? If you use this type, please submit drawings and describe the advantages or disadvantages derived from the use of this design.

4. Are any of your boilers fitted with combustion chambers? If so, please supply drawings and state what results have been obtained with this method of construction.

5. Have you constructed any boilers with fire-boxes of any other material than copper? If so, what have been the results compared with copper fire-boxes of the same design.

6. What shape and size of firehole do you find the most suitable? Do you employ any special door or other special means of air- admission? Do you use a ring joint or dished joint between the inner fire-box plate and back plate? If the former, how is it fastened?

7. What is the proportion between the total grate area, air-space in the firegrate, and total tube area? Are any of your boilers fitted with rocking or drop grates?

8. In very long boilers, do you employ any form of intermediate support for the barrel of the boiler?

9. Which type of front tube-plate do you fit your boilers with, viz., drum-head, or plate with extension fitted to the cylinder casing?

10. What material are your tubes constructed of? Give reasons for the adoption of the metal or alloy you employ.

11. What are the dimensions of tubes used in your standard type of boiler, including thickness at each end?

12. What is the method employed in fixing tubes in your boilers? Kindly give a description, with sketches, of any special machines or device employed for this purpose. Are the tubes expanded in any particular order?

13. Have you had any experience with Serve tubes? If so, please supply particulars.

14. Are you troubled with :

a) Pitting of steel or iron tubes?

b) Excessive wear or fracture of copper or brass tubes just inside the copper tube-plate?

What steps do you take to counteract these defects? Have you tried galvanized steel or iron tubes, and, if so, with what results?

15. Do you employ ferrules in tubes? If so, with what object in view, *e. g.* :

a) Keeping the tube tight?

b) Protecting the end of the tube from the action of the fire?

What taper and thickness of ferrule do you use? Do you bead the ends of your tubes and, if so, with what results? If this has been tried and given up, what cause led to its being discontinued?

16. How are your tubes arranged in the tube-plate, *i. e.*, in vertical or horizontal rows? State the reason for your practice. What space is allowed between the tubes?

17. Do you employ pressures above 180 lb. per square inch and, if so, have any special means had to be taken to cope with these pressures, especially in the keeping of the tubes tight and in maintaining the fire box tube-plate in good condition?

18. Has it been found that any special spacing of the tubes or stays has led to a decrease in the trouble experienced from cracked corners of the tube-plate? Have you tried cold hammering of the copper tube-plate in order to harden it and, if so, with what results?

19. Do you use an extended smoke-box? If so, what advantages are derived from it.

20. In your latest standard types of boilers do you fit a steamdome and, if not, what device is in use to obtain dry steam?

21. What material is used for lagging your boilers? Are the boilers lagged inside the cabs? If you have made any tests to ascertain the relative efficiency of different lagging materials, kindly give particulars and results.

22. Do you employ any system of thermal storage and, if so, what advantage do you derive from it?

LITTERA *C*,

1. What process, or processes, do you use for softening water? Give particulars of the chemical treatment, stating what chemicals are used; and, without describing well-known methods, give details of any special methods or apparatus you employ, or any special details connected with the working of the ordinary methods of treatment which you have found advantageous. What precautions are observed to ensure the treatment being properly carried out?

2. State whether you are satisfied with the results obtained and, if possible, give figures shewing the saving effected in :

1. Fuel;
2. Cost of cleaning and retubing boilers;
3. Cost of repairs to and life of boilers;
4. Cost of water (*i. e.* by being able to use water which can be obtained cheaply, instead of having to purchase expensive water of better quality.)

3. How do you deal with waters of which the hardness is mainly or largely due to calcium and magnesium sulphates, chlorides or nitrates? Do you soften such waters, and if so, what precautions do you take to prevent priming of the boilers caused by sodium salts introduced in softening?

4. Have you used barium hydroxide, barium carbonate, or barium aluminate in softening water containing sulphates. If so, please give particulars, results and cost of treatment, and state whether you find it pays.

5. Have you made any attempt to ascertain the quantity of sodium salts present in the water of locomotive boilers when priming commences? If so, please give particulars and results of these experiments.

6. Do you use, or have you used, disincrustants placed directly in the boilers, instead of treating the water before use? If so, state the nature of the materials used, and the results obtained.

7. In connection with water softening or the use of disincrustants, have you been troubled with excessive leakage of boiler tubes or stays? If so, kindly give particulars, stating what you conceive to be the cause of the leakage and whether any and, if so, what means you have found effectual in preventing or lessening this leakage.

8. On what portions of the interior of the boiler do the following defects occur :

1. Cracks.
2. Pitting.
3. Grooving.
4. General surface corrosion.

9. When the boilers undergo heavy repairs, are any notes made on the repair sheets as to the defects mentioned in question 8? Are sketches made on the sheets illustrating the actual nature, position and dimensions of these defects? If so, kindly supply some of these sheets chosen from amongst those giving the most characteristic defects.

10. What are the methods employed in the construction of boilers to prevent any of the defects referred to in questions 8 and 9? Have modifications been carried out in the design of the boilers with this end in view? What is the breadth of the water-spaces in the fire-box? Where is the feed water delivered, and in what manner?

11. Are the boilers washed out with cold or hot water? What are the mean mileages between two washings out? In fixing these mileages, is account taken of the quality of the water? What is the time allowed for cooling down before the boiler is washed out with cold water? What pressure of water is used for washing out? If any system of washing out with hot water is employed, kindly describe this fully.

12. Is blowing off a portion of the water under pressure resorted to in order to prevent the formation of deposit and to check priming? If this practice is carried out, at what time and after what intervals is it done? What means are adopted to remove the water? Shew by sketches cock and its design.

13. If you have any waters which are specially corrosive to boilers, but which by analysis are

not found to contain free mineral acid, please give analyses stated in parts per 100,000 shewing (if possible) the amounts of :

Lime (Ca O).
Magnesia (Mg O).
Soda (Na_2 O).
Alkalinity (as Ca CO_3).
Sulphuric Anhydride (SO_3).
Nitric Anhydride (N_2 O_5).
Chlorine (Cl).
Carbon Dioxide (CO_2), free.
Total Solid Matter at 130° C.

14. Have you tried to prevent corrosion by coating the insides of boilers with Portland cement or any kind of paint, or by treating the water with a definite excess of lime or other chemical to neutralize carbonic or other acid, or by introducing chemicals or other substances into the boilers? If so, please give full particulars and results.

15. Do you use zinc plates in your boilers? If so, explain, with sketches, the method of application and the results as regards :

1. Prevention of incrustation.
2. Prevention of pitting and corrosion.

16. What metal or alloy is used or has been tried for fire-box stays ; if any metal other than copper or iron, give composition. What advantages have been found to result from the use of these other metals or alloys? Is any trouble experienced with stays breaking; if so, please state where these fractures occur and indicate :

1. The position in the stay itself.
2. The position of the stays in the box.

Are any special means adopted to detect fractures? Is any type of flexible stay used? Are you troubled with stay heads burning away and dropping off in the fire-box? If so, what means have been adopted or tried to prevent this, and with what result?

17. Have you tried lining the fire-box or any part of it with firebricks or fireclay slabs to protect the stays from the action of the fire and to promote better circulation of the water in the fire-box ; if so, give results, and state the nature and composition of fire-resisting material used.

[621 .133.3 & 621 .133.7]

REPORT N° 9

Russia

By N. ANTOCHINE,

ENGINEER OF TECHNOLOGY AND OF WAYS OF COMMUNICATION,
MEMBER OF THE TECHNICAL COUNCIL OF THE MINISTRY OF WAYS OF COMMUNICATION OF RUSSIA.

LITTERA *A*.

Boilers with smoke tubes; precautions in constructing tubes and tube-plates.

In Russia the ministry of ways of communication controls, in accordance with the law, the construction, the management, the maintenance, etc. of the railways; it follows that the selection of the types of rolling stock is left to its discretion. It tries to make the types of rolling stock as uniform as possible; it however allows the types it has adopted to be departed from, but only in cases where there are proper reasons therefor. Owing to this peculiarity, the greater number of the answers received to the list of questions refer to one and the same type, called the normal type. This type of locomotive is intended to work under very varying conditions and in different climates; feed-water of different origins and varying kinds of fuel are used, and the conditions of maintenance and supervision vary. Only a few of the answers relate to the most recent types of the modern locomotive, to one or two types of goods locomotives, to two or three types of passenger locomotives.

*

A detailed list of questions was sent to thirty State railways and privately-owned railways. Twenty-one of those railways sent answers, a summary of which is given in this report.

Question 1. — *What type of boiler do you use? Belpaire or round-topped? Please forward drawings of your latest standard types.*

Figure 1 shows the boiler of the normal type of goods locomotive with four coupled axles, and figure 2 the more powerful boiler used both for 1-4-0 goods locomotives and 2-3-0 passenger locomotives. The use of this latter boiler is becoming very extensive.

The crowns of the fire-boxes of both boilers are flat and connected withe the top of the fire-box shell by Belpaire stays. In the second boiler the top of the fire-box shell is also flat; its construction presents the following two peculiarities :

The two rows of stays next to the tube-plate are expansion stays, and moreover part of the crown is connected with the side walls by means of diagonal stay-bolts.

The crown in the most recent passenger locomotives is stiffened in a similar way to that of the two types just mentioned.

Among the older types, cylindrical fire-box crowns or fire-box shells are still to be found; for instance on the Baldwin locomotives, built in 1897, where part of the crown stays were arranged radially; but when the crown was renewed, it was made flat and the stays were arranged vertically.

Figures 3 to 5 represent the boiler of the new 1-2-2 type of locomotive.

As regards shape, this boiler only differs by the skewness at the bottom of the fire-box. The staying of the crown is effected by Belpaire stays.

Question 2. — *If you use round-topped boilers, do you use roof-bar or radial stays on the fire-box crownsheets? Kindly state what special advantages you find from each type.*

Three railway systems own a somewhat small number of locomotives (from 10 to 36) with round-topped fire-box and stays arranged radially; these stays are replaced, on one of the systems, by vertical stay-bolts; the two others retain radial stays and obtain very satisfactory results.

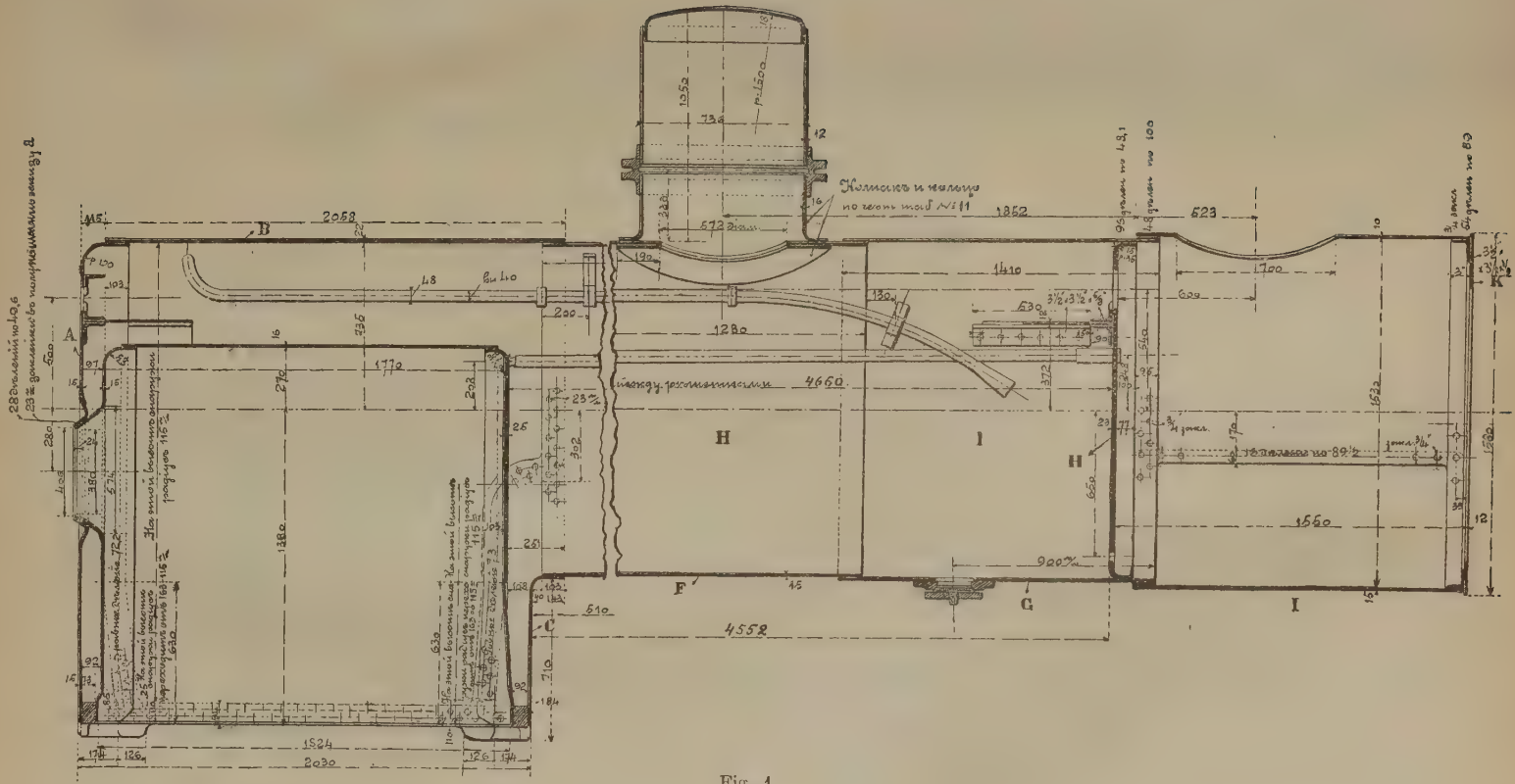


Fig. 1.

At the back of the fire-box shell : at this height outside, the radius changes from 163 to 115 millimetres (6 7/16 to 4 1/2 inches).
At the front of the fire-box, ditto.
The other notes refer to the spacing of the rivets. For instance at the fire-hole, 28 divisions of 49·6.

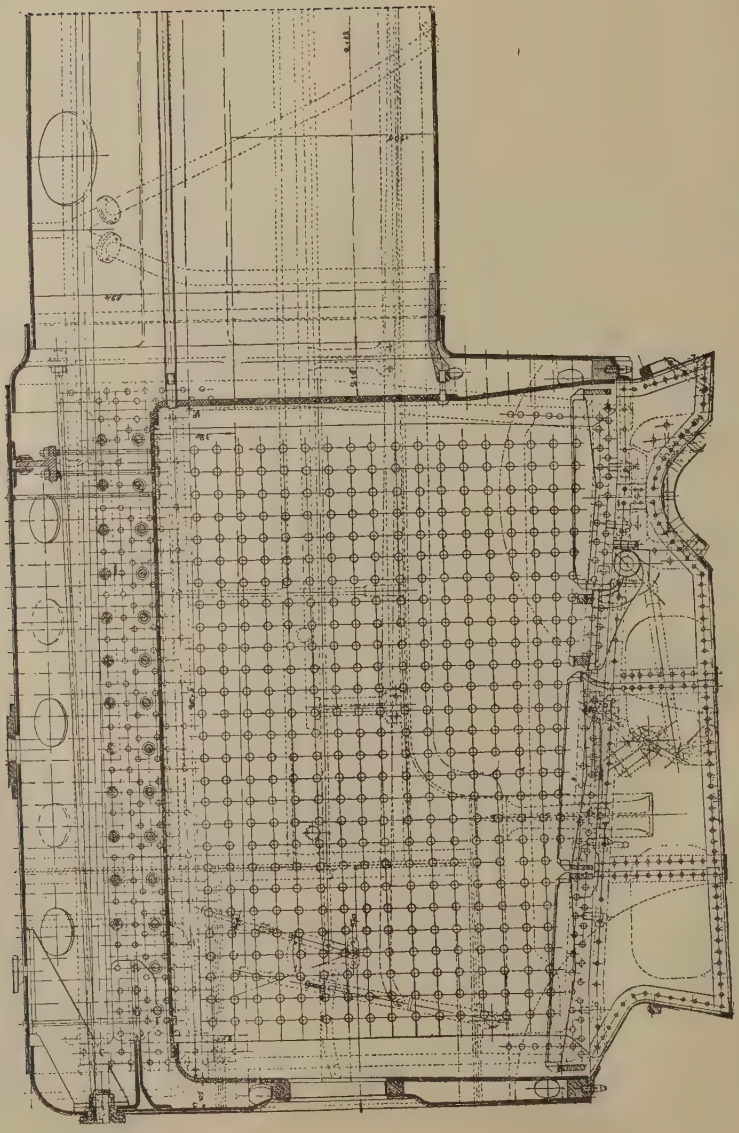


Fig. 2.

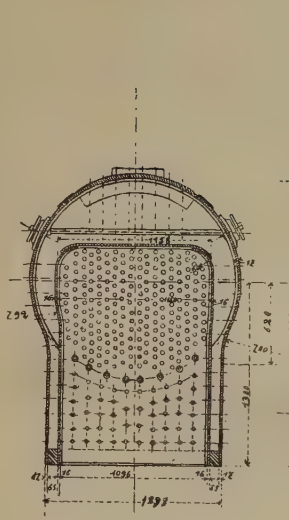


Fig. 4.

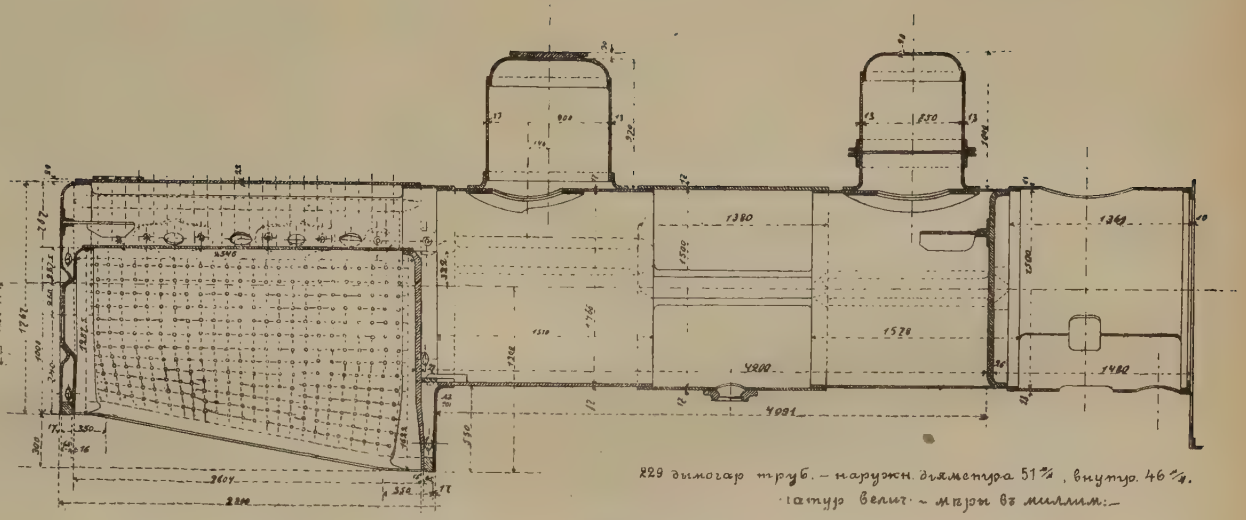


Fig. 3.

229 smoke tubes; external diameter, 51 millimetres (2 inches); internal diameter, 46 millimetres (1 13/16 inches). The dimensions are given in millimetres.

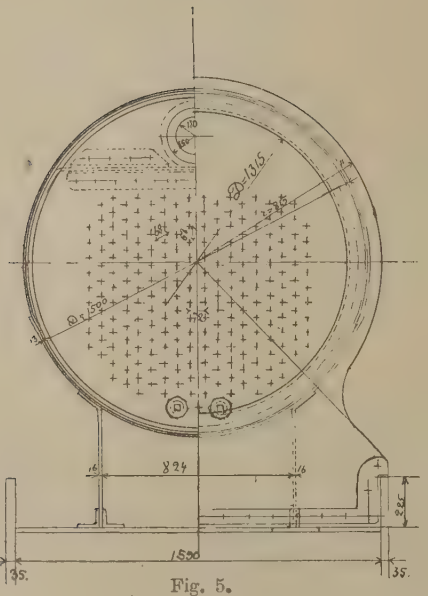


Fig. 5.

QUESTION 3. — *Have you any locomotives fitted with cylindrical fire-boxes? If you use this type, please submit drawings and describe the advantages or disadvantages derived from the use of this design.*

Cylindrical fire-boxes are not used in Russia.

One boiler with water-tube fire-box on the Brotan system is in use on a 0-4-0 goods locomotive, No. 477, on the Moscow-Kazan line; another boiler of this pattern will be used on a 2-3-0 locomotive belonging to the same line; locomotive No. 447 has been in use since July 1907, about a year and a half, a rather short time; the feed-water used for it has from 6 to 17·5 German degrees (7·4 to 21·6 English degrees) of hardness. The boiler is washed out after the locomotive has run 1,100 to 1,200 versts (730 to 800 miles); nevertheless after a service of eight months a very adherent layer of scale, 1 to 2 millimetres ($^3/_{64}$ to $^3/_{32}$ inch) thick, was formed. Owing to the accumulation of the scale, one of the tubes showed a bulge; it was replaced in a day. The steam obtained is wetter than that supplied by the locomotive boiler of the normal type; however the economy of fuel attains 10 to 15 per cent, to judge from the distance of 25,567 versts (16,945 miles) run in eight months. This boiler appears to work cheaply and to be full of promise.

The South-Eastern Railways have two locomotives of the 0-4-0 type, Nos. 675 and 708, equipped with Brotan boilers. These two locomotives have been running

regularly since the end of 1907. By 1 February 1909 they had run distances of 37,098 and 37,001 versts (24,588 and 24,524 miles) respectively. The coal consumptions of these two locomotives as well as those of the normal locomotives of the same type, are given in the following table :

—	Per train-verst, in kilograms.	Per train-mile, in lb.	Per wagon-verst, in kilograms.	Per wagon-mile, in lb.
Locomotive No. 675	26·5	88·14	0·708	2·355
Locomotive No. 708	28·5	94·79	0·736	2·448
Normal locomotive from	28·75	95·62	0·736	2·448
Normal locomotive to	30·7	100·01	0·792	2·634

The water tubes are cleaned out through the openings without any difficulty; the feed water of the boilers is hard, that is to say it has 35 to 70 degrees (43 to 86 English degrees) of hardness.

Question 4. — *Are any of your boilers fitted with combustion chambers? If so, please supply drawings and state what results have been obtained with this method of construction.*

The Russian railways possess no locomotive having a boiler fitted with a combustion chamber. Since the middle of 1908 three locomotives belonging to different lines have been fitted with a brick arch, of American origin.

Question 5. — *Have you constructed any boilers with fire-boxes of any other material than copper? If so, what have been the results compared with copper fire-boxes of the same design.*

Fire-boxes of iron (side walls) are extensively used on the Vladicaucasus line (out of 809 locomotives, 302 are so equipped); up to the present the results have been good, but the use of hard water results in corrosion of the iron plates.

Eight other administrations are using, as an experiment, iron for the fire-boxes partly in the form of full sheets, partly for tube-plates and back plates. The results of these experiments vary, that is to say, that they are good on lines where the water has not more than 20 degrees (24·7 English degrees) of hardness and bad where the water has from 20 to 90 degrees (24·7 to 111 English degrees) of hardness. The

iron plates require more looking after than the copper plates, owing to leaks at the smoke tubes. In order to prevent such leaks, two administrations are trying the interposition of thin liners of copper (1 to 1·5 millimetres [$^3/_{64}$ to $^1/_{16}$ inch] thick), placed between the tube-plate and the smoke tube; up till now no definite results have been obtained.

Question 6. — *What shape and size of firehole do you find the most suitable? Do you employ any special door or other special means of air-admission? Do you use a ring joint or dished joint between the inner fire-box plate and back plate? If the former, how is it fastened?*

Most of the fire-holes are of two shapes : either round, or rectangular with the corners rounded. Many railways prefer a hole without special frame (the Webb joint); others prefer a hole with a ring having a width not exceeding 50 millimetres (1 $^{31}/_{32}$ inches). The latter shape makes it easier to scrape the scale from the surfaces.

On the lines where the boiler feed-water is hard, fire-holes of special shapes, as shown in figures 6, 7 and 8, are put in when the boilers are generally overhauled.

The frame of the hole is sufficiently removed from the action of the fire to enable the rivets connecting the sheets with the ring to remain tight.

The fire-doors are of two types :

a) With one or two wings, or circular with a diameter of 380 millimetres (1 ft. 2 $^{15}/_{16}$ in.), or oval with D′ = 290 millimetres (11 $^7/_{16}$ inches) and D″ = 420 millimetres (1 ft. 4 $^1/_2$ in.);

b) Sliding towards the two sides, the hole being rectangular.

Small supplementary doors for the admission of air are not used when wood or coal is used for firing. When petroleum residues are used for this purpose, the doors used in the case of coal-firing are closed, and the air enters the fire-box from below, through the ash-pan doors. It first passes over heated bricks which partly cover the copper walls of the fire-box and which do the work of grate bars. The arrangement of the bricks and of the air access varies with the design of the burners used for the petroleum residues. The connexion between the inner fire-box and the ouside is always effected by a frame; dished joints are not used. The method of connection is shown in the annexed figures.

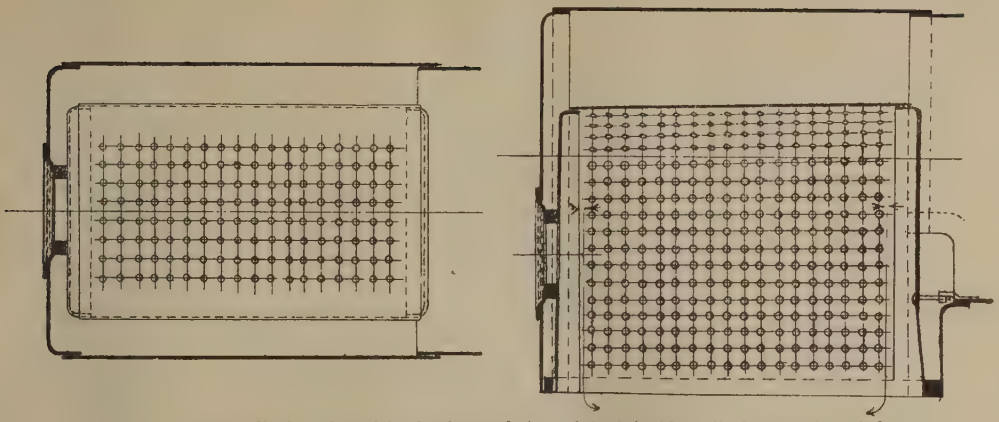


Fig. 6. — Longitudinal section of the fire-box and view of the left side wall of the fire-box shell.

Design of the builder. Variation I, by the technical office.

Fig. 7.

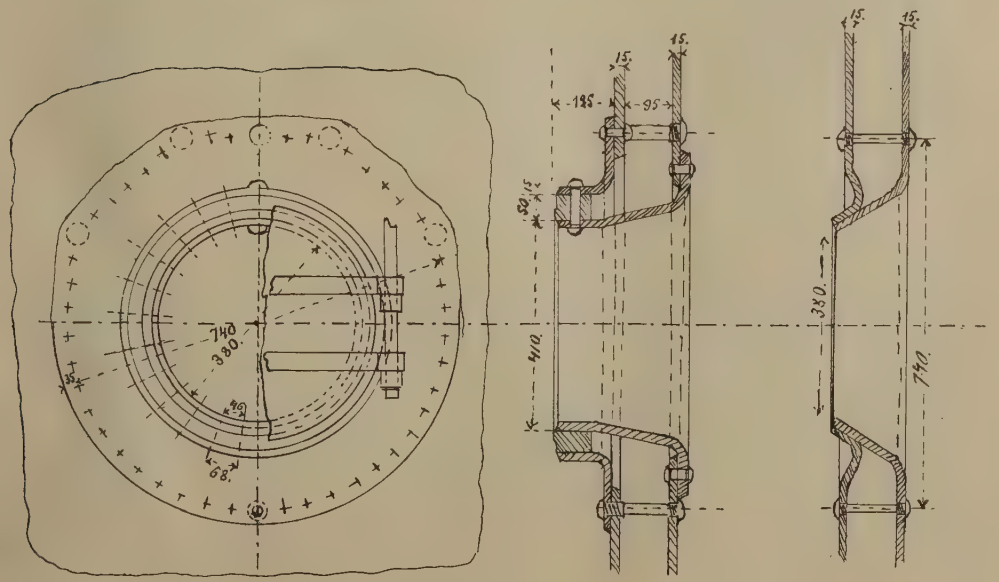


Fig. 8.

Question 7. — *What is the proportion between the total grate area, air-space in the fire-grate, and total tube area? Are any of your boilers fitted with rocking or drop grates?*

The Russian railways use several classes of fuel : petroleum residues, crude petroleum, coal, anthracite, lignite and wood.

Petroleum residues and crude petroleum make a grate unnecessary, and this is replaced by bricks arranged in different ways with different air spaces in between. The size of these air spaces varies, in the different systems, between 0·3 to 0·15 of the original grate area. The tube area remains the same.

In locomotives fired with coal or with wood, the useful grate area as compared with the total grate area varies with the nature of the fuel and its quality, from 57 to 26 per cent; the higher figures refer to wood and lignite.

The ratio of the total tube area to the useful grate area varies between 0·22 to 0·08.

Rocking or drop grates are only used on the Perm line, which uses coal containing 8 to 12 per cent of ash and 4 to 6 per cent of sulphur.

This railway considers that rocking grates are convenient and useful and effect a saving in fuel of from 3 to 5 per cent.

Question 8. — *In very long boilers, do you employ any form of intermediate support for the barrel of the boiler?*

Supports are always used for the barrel of the boilers; these supports are generally rigid and fixed to the frame plates of the locomotive. Supports made of thinner plate which can bend so as to allow for the expansion of the boiler have also been used, but experimentally only; up to the present, these experiments have given good results.

Question 9. — *Which type of front tube-plate do you fit your boilers with, viz., drum-head, or plate with extension fitted to the cylinder casing?*

In the most recent locomotives of the different types, the front tube-plate is generally cylindrical with a flanged edge. This plate is either introduced, with its flanged edge, into the barrel; or else it has a larger diameter than the barrel, so as to make the smoke-box larger, and in that case it is connected with the barrel of the boiler by means of an angle-iron ring.

Another shape of smoke-tube tube-plate, non-cylindrical, was often used on the older locomotives and there would be no reason against adopting it again in the future, if the rest of the design of the locomotive could benefit by it.

Question 10. — *What material are your tubes constructed of? Give reasons for the adoption of the metal or alloy you employ.*

The smoke tubes are made exclusively of ingot iron.

This material, which is much cheaper than brass, works very well, requires no special maintenance, and as regards conductivity, is practically equivalent to brass.

Question 11. — *What are the dimensions of tubes used in your standard type of boiler, including thickness at each end?*

The smoke tubes of the boilers of the most recent locomotives have as a rule an external diameter of 51 millimetres (2 inches), but sometimes also one of 45 millimetres (1 $^{13}/_{16}$ inches); at the fire-box ends they are contracted to 45 and 40 millimetres (1 $^{13}/_{16}$ and 1 $^{9}/_{16}$ inches) and at the smoke box ends they are enlarged to 53 and 47 millimetres (2 $^{3}/_{32}$ and 1 $^{27}/_{32}$ inches) respectively. The thickness of the tubes is nearly always 2·5 millimetres ($^{7}/_{64}$ inch) and only rarely 3 millimetres ($^{1}/_{8}$ inch). Near the fire-box the tubes often have copper ends joined on, which have a thickness of 3 millimetres ($^{1}/_{8}$ inch), sometimes of 4 millimetres ($^{5}/_{32}$ inch), and very rarely of 5 millimetres ($^{3}/_{16}$ inch); no such ends are put on at the smoke-box ends.

Question 12. — *What is the method employed in fixing tubes in your boilers? Kindly give a description, with sketches, of any special machines or device employed for this purpose. Are the tubes expanded in any particular order?*

The tubes in recent cases are fixed in the boiler by means of roller-expanders. The method is shown in figure 9. If old tubes begin to leak, either a special tube-expander is used, or else also a caulking chisel. The roller-expander is shown in figure 10.

At the smoke-box ends, the tubes are always in direct contact with the tube-plate.

At the fire-box ends there is either direct contact, or else devices of two kinds are interposed.

These devices are either a thin tube of copper, 1 to 1·5 millimetre thick ($^{3}/_{64}$ to $^{1}/_{16}$ inch), a little longer than the thickness of the plate, or else three brazed rings of copper, for which grooves are made in the tube-plate. In both cases, the tube is forced against the tube-plate by the ordinary roller-expander. These two kinds of devices are intended to prevent leakage at the tubes. The figures illustrating the roller-expander and the caulking chisels make further description of these tools unnecessary.

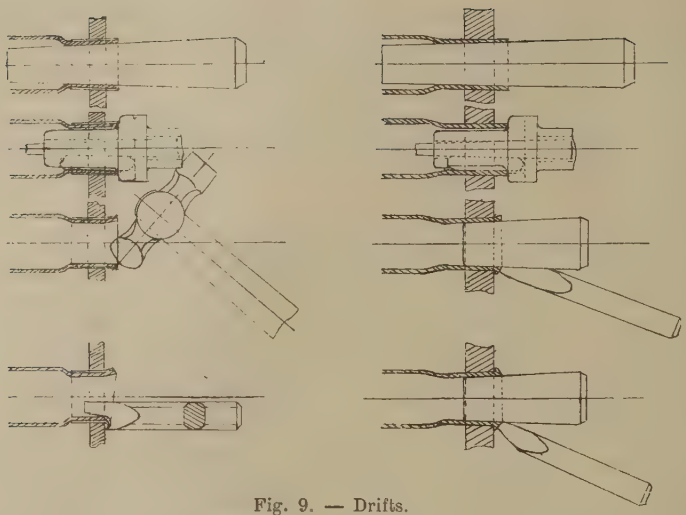


Fig. 9. — Drifts.

Question 13. — *Have you had any experience with Serve tubes? If so, please supply particulars.*

Serve tubes are being tried on the Warsaw-Vienna line and effect a certain saving in the fuel; no other remarks have been made on the subject. The other railways do not use these tubes.

Question 14. — *Are you troubled with*

a) Pitting of steel or iron tubes?

b) Excessive wear or fracture of copper or brass tubes just inside the copper tube-plate?

What steps do you take to counteract these defects? Have you tried galvanized steel or iron tubes and, if so, with what results?

The iron smoke tubes rust and show pitting after they have been in use for about five years, on the lines where the water is hard. This phenomenon is looked upon as normal and no special measure is taken except in order to prevent any irregularities in the train service which might result, even occasionally, from any defects of the tubes. The tubes, for this reason, are tested by means of an internal hydraulic pressure of 25 atmospheres (367·65 lb. per square inch), and sometimes also by means of an external hydraulic pressure of 20 atmospheres (294·12 lb. per square inch). The Russian railways do not use brass or copper tubes.

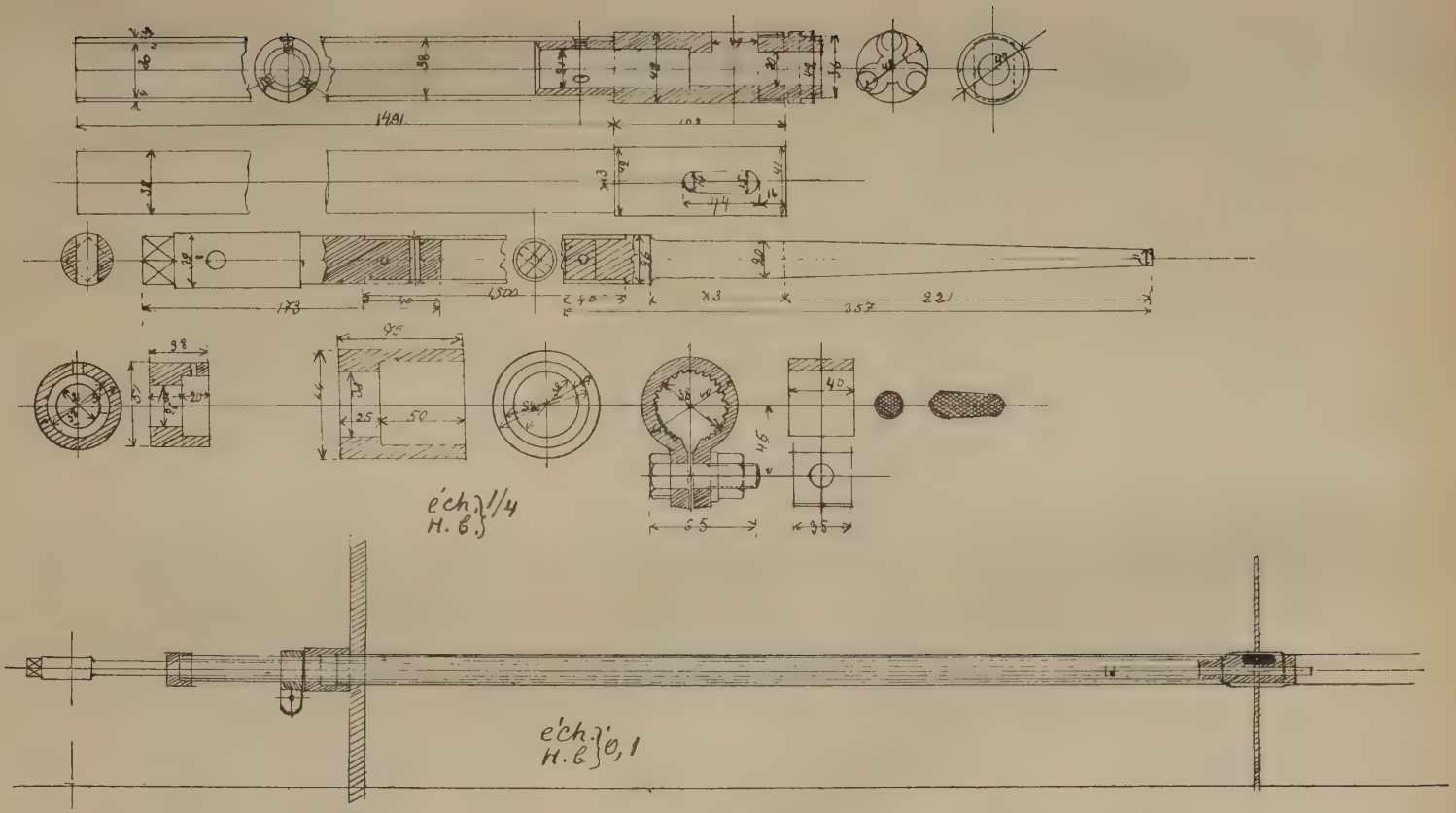


Fig. 10. — The Jarrow tube-beader.

QUESTION 15. — *Do you employ ferrules in tubes? If so, with what object in view, e. g. :*

a) Keeping the tube tight?

b) Protecting the end of the tube from the action of the fire?

What taper and thickness of ferrule do you use? Do you bead the ends of your tubes and, if so, with what results? If this has been tried and given up, what cause led to its being discontinued? To what causes do you attribute the leakage of the tubes at the fire-box? What means do you adopt to counteract it?

Sometimes, but rarely, ferrules are used inside the tubes. Ferrules are sometimes used at the fire-box ends, in order to keep the joint between the tube and the plate tight, or in order to protect the ends of the tubes from being burnt. Many railways refuse to use ferrules, as they have recognized that they do not fulfil either purpose and on the contrary promote the accumulation of soot and of cinders near the ends of the ferrules and are consequently harmful. Different materials have been tried for ferrules; iron, cast iron, copper, porcelain. The ferrules are of cylindrical shape, with one end rounded, to facilitate beading over. The ferrules are 2·5 to 3 millimetres thick ($^3/_{32}$ to $^1/_8$ inch).

The smoke tubes are beaded over at their fire-box ends and this is considered a good method of fixing; at the smoke-box the ends are sometimes left unbeaded and projecting 2·5 millimetres ($^{31}/_{32}$ inch) beyond the surface of the tube-plate. The ends are left straight if wood is used for firing, in which case the ends do not become burnt in the smoke-box; it is then possible to cut off a piece of the copper end at the fire-box end and put in the same tube again within having to braze on a new end of copper or of iron.

QUESTION 16. — *How are your tubes arranged in the tube-plate, i. e., in vertical or horizontal rows? State the reason for your practice. What space is allowed between the tubes?*

The boiler locomotives recently constructed all have the tubes arranged in vertical rows in order to facilitate the ascent of the bubbles of steam formed at the circumference of the tubes; instances of the arrangement of the tubes are shown in figures 1, 4 and 11. It will be seen that there is a certain want of uniformity in these figures, as regards the arrangement of the tubes in the upper corners, relatively to the middle of the plate; this has as object the prevention of the appearance of cracks in the interspaces of the fire-box tube-plate, and the increase of the distance between the tube holes. It follows that the spacing of the tubes in the most recent Russian locomotives is either normal, or increased, in accordance with the design of the arrangement of the tubes. The following cases occur : *a*) the centres of the tubes

are 66 millimetres (2 $^{5}/_{8}$ inches) apart in the one direction, and 70·6 millimetres (2 $^{25}/_{32}$ inches) in the other; that is to say the distance between the tube walls is 15 or 19·5 millimetres ($^{19}/_{32}$ or $^{49}/_{64}$ inch); *b*) they are 61·8 to 64·8 millimetres (2 $^{7}/_{16}$ and 2 $^{9}/_{16}$ inches) apart in the one direction and 65·6 to 67 millimetres (2 $^{37}/_{64}$ to 2 $^{41}/_{64}$ inches) in the other; that is to say the distance between the tube walls is 10·6 to 13·8 millimetres ($^{27}/_{64}$ to $^{35}/_{64}$ inch) in the one direction and 14·6 to 16 millimetres ($^{37}/_{64}$ to $^{5}/_{8}$ inch) in the other. The increase is attained at the fire-box ends not between the walls of the tubes but between the holes; some of these holes having diameters of 47 and 48 millimetres (1 $^{27}/_{32}$ and 1 $^{57}/_{64}$ inches) are reduced at the corners to 42 millimetres (1 $^{21}/_{32}$ inches), so that the distances between the holes are increased by 5 to 6 millimetres ($^{3}/_{16}$ to $^{1}/_{4}$ inch) and attain 22 ($^{7}/_{8}$ inch), and sometimes even 24 millimetres ($^{15}/_{16}$ inch).

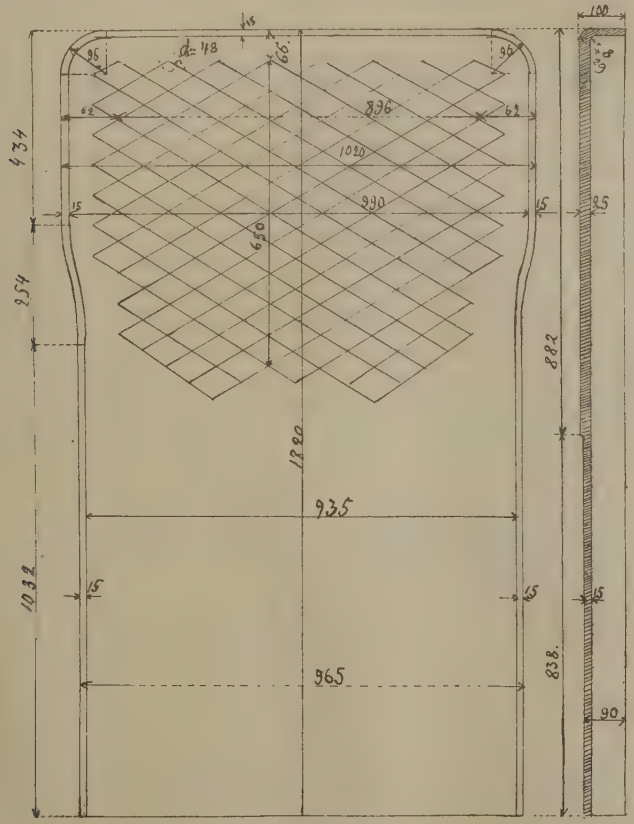


Fig. 11.

QUESTION 17. — *Do you employ pressures above 180 lb. per square inch and, if so, have any special means had to be taken to cope with these pressures, especially in the keeping of the tubes tight and in maintaining the fire-box tube-plate in good condition?*

Pressures higher than 180 pounds per square inch, and up to 206 pounds per square inch, are only used on the Vladicaucasus, the Orient and China, and the Riazan-Ural lines. The first of these railways states that it is wholly satisfied with the use of this pressure and has found no difficulty; the second has eight locomotives working at that pressure; it is observed that stays break frequently, but there is no trouble as regards the tightness of the tubes and the behaviour of the tube-plate; the Riazan-Ural line has been using these locomotives for the last two years and the Vladicaucasus line for about eight years.

QUESTION 18. — *Has it been found that any special spacing of the tubes or stays has led to a decrease in the trouble experienced from cracked corners of the tube-plate?*

Have you tried cold hammering of the copper tube-plate in order to harden it and, if so, with what results?

What methods do you adopt for repairing the different defects affecting the tube-plates?

In the goods locomotives of normal type, built before 1893, the tubes in the top row near the corner of the tube-plate were 50 millimetres (1 $^{31}/_{32}$ inches) apart, centre to centre; in the latest locomotives of the same type, this distance has been increased to 70 millimetres (2 $^{3}/_{4}$ inches); the tubes in the last vertical rows nearest the vertical corners were the same distance apart. This increase has the object of preventing the formation of cracks in the bends of the tube-plate; it has given good results. The fisrt row of the Belpaire stays is 200 millimetres (7 $^{7}/_{8}$ inches) from the tube-plate and 180 millimetres (7 $^{3}/_{32}$ inches) from the back plate; expansion stays are sometimes used for the first row; they are not secured to the crown of the fire-box but to fixed yokes attached to the shell, allowing for vertical expansion; using a row of articulated stays also reduces the production of cracks in the tube-plate. The stays of the tube-plate and of the back plate are at 80 millimetres (3 $^{5}/_{32}$ inches) from the side walls, and this distance has been the practice for more than fifteen years; it gives a sufficient guarantee against frequent fracture of the stays. Cold hammering of the copper tube-plate has never been practised.

QUESTION 19. — *Do you use an extended smokebox? If so, what advantages are derived from it.*

In the compound locomotive of normal type, the capacity of the smoke-box is 10·5 times that of the low-pressure cylinder; in the most recent locomotives, this ratio is increased to 11.

In the tandem compound locomotives, this ratio is materially greater and attains, like in the superheated-steam locomotives with ordinary cylinders, seventeen times the capacity of the cylinders. Thus there are three different ratios.

The largest dimensions of the smoke-boxes to be found on any of these locomotives are : diameter 1,712 millimetres (5 ft. 7 $^{3}/_{8}$ in.), and length 1,541 millimetres (5 ft. $^{11}/_{16}$ in.). It has not been found on the Russian railways that a large smoke-box exercises any particular influence.

Question **20.** — *In your latest standard types of boilers, do you fit a steam-dome and, if not, what device is in use to obtain dry steam ?*

All the locomotives of the most recent types are fitted with a steam dome. As an experiment, a boiler has been fitted with two domes, connected by a tube, in order to obtain dry steam, to eliminate any water-hammer action in the cylinders, and to increase the store of steam in the boiler. The addition of the second dome gave the expected results as far as the two first points were concerned. Their use has however not become general ; they have simply led to an increase in the size of the domes of new locomotives. With a single dome, of double the capacity, more water is however carried over than if there are two domes connected by tubes.

Several devices have been tried in order to obtain dry steam. Some of them resemble fans ; the steam must flow between blades which throw the water back down towards the bottom.

Question **21.** — *What material is used for lagging your boilers ? Are the boilers lagged inside the cabs ? If you have made any tests to ascertain the relative efficiency of different lagging materials, kindly give particulars and results.*

Several means are adopted for protecting boilers against cooling, but only the ordinary ones :

a) Thin sheet metal around the boiler at a distance of 50 to 60 millimetres (1 $^{31}/_{32}$ to 2 $^{3}/_{8}$ inches) thus retaining a layer of air ;

b) The same arrangement, but a layer of felt 10 to 30 millimetres ($^{3}/_{8}$ to 1 $^{3}/_{16}$ inches) thick is placed in the intermediate space ;

c) The same arrangement, but in addition to the felt there is a layer of wood 25 to 30 millimetres (1 to 1 $^{3}/_{16}$ inches) thick ;

d) The wood is sometimes replaced by a layer of compressed cork, and the felt by asbestos or paper pulp.

In most cases, the same lagging is used inside the cab as elsewhere ; a small number of railways put less lagging inside the cab.

*

The systems of protection mentioned above are considered sufficient and the administrations do not think it necessary to try any others; one of them has used a lagging built up of small magnesia bricks, but had to give them up on account of the price and the difficulty of obtaining bricks for renewals.

Question 22. — *Do you employ any system of thermal storage and, if so, what advantage do you derive from it?*

As an experiment, two systems for the storage of heat have been tried :

1° A second steam dome connected by a tube with the first dome containing the head of the regulator;

2° A special tank containing water at the same temperature and pressure as that in the boiler; the capacity of this tank is 1·45 cubic metres (320 English gallons).

The supplementary steam dome, tried on the Libava-Romny line, proved advantageous :

a) At the moment of starting; in the case of the double dome practically no water passes from the boiler to the cylinders;

b) On steep gradients, as a reserve of steam.

These two advantages of the supplementary steam domes, are however not important enough to induce the administration to complicate the construction of the locomotive in this way, and it is for this reason that the use of second domes has not become generalized on this line. The water tank can, at the option of the driver, be placed in communication with the steam space in the boiler, the water space or the injector; it can also be cut off. One commences by allowing the air, which is driven out by hot water entering from the boiler, to escape through the injector. If communication between the tank and the injector is cut off, and that between the tank and the steam and water spaces of the boiler is opened, the hot water from the tank flows of itself into the boiler; if the reserve of hot water in the tank is exhausted before the locomotive reaches the gradient, the tank acts like a second steam dome. Rather extensive trials have been made; the Moscow-Kursk line made trials in 1896 with very satisfactory results, more especially with a saving of fuel which at first amounted to 15 per cent, but this saving was not kept up in current practice. The same observation was made on the Perm, the Zlato-Ustov and the Riazan-Ural lines, when they tried these tanks, so that their use has at present become generalized neither on the State lines nor on the privately-owned lines. No other system of storing heat, besides the two just mentioned, is used on the Russian railways.

CONCLUSIONS.

The present well-marked tendency on Russian railways, as far as locomotive boilers are concerned, is :

1° To generalize (standard) both as regards design and as regards dimensions;

2° To strengthen the crown by means of Belpaire stays;

3° To stay the shell of the fire-box without using roof bars;

4° To substitute mild steel for copper in the case of fire-boxes, althogh most of the lines still use copper;

5° To use only mild steel for smoke tubes. These are cylindrical without ribs inside or outside;

6° The absence of heat storage on the most recent types of boilers.

LITTERA *C*.

Damages to boilers, pitting, cracks and corrosions. — Means employed for preventing these damages. — Purification of the water, and disincrustants or anti-fouling compounds.

Answers have been received from twenty State or privately-owned railways, representing the majority of the Russian railways both as regards number and extent of the systems.

Most of the Russian railways have pure water available, having, for instance on the Transbaikal lines, from 3 to 14 German degrees (3·7 to 17·5 English degrees) of hardness; on other lines the hardness varies from 8 to 25 degrees (10 to 31 English degrees); consequently no system of softening or of purifying water is adopted.

We know that on lines utilizing good water, the iron smoke tubes are not taken out for cleaning, except severy seven years; a locomotive runs 200,000 versts (132,560 miles) in that time, and the layer of scale on the tubes is only 0·75 to 1 millimetre ($^1/_{32}$ to $^3/_{64}$ inch) thick. The boilers are washed out after running between 1,500 and 2,000 versts (between 1,000 and 1,325 miles) in the regular service. A small number of lines in the south or south east of Russia, or near the Caspian sea, only have hard water available. The lines in those parts of Russia as well as those in Siberia, occasionally suffer from a want of water, so that they sometimes find it necessary to send trains carrying water to quite considerable distances.

QUESTION 1. — *What process, or processes, do you use for softening water? Give particulars of the chemical treatment, stating what chemicals are used; and, without describing well-known methods, give details of any special methods or apparatus you employ, or any special details connected with the working of the ordinary methods of treatment which you have found advantageous. What precautions are observed to ensure the treatment being properly carried out?*

The removal of impurities is effected on one of the lines in Central Asia. The Jagn and Krug processes consist in evaporating water in boilers; the steam is condensed by means of other water and the distillate is a pure water which can be used for feeding boilers. The distillate only has a hardness of 2 to 3 German degrees (2·4 to 3·7 English degrees), but the cost is very high and varies from 8 to 20 rubles per cubic sagene (0·672 to 1·679 pence per cubic foot) treated; the water had a hardness of 90 to 100 German degrees (112 to 124 English degrees) before it was distilled. The high cost of distillation leads the administrations to two measures, when these can be applied : the carriage of water in special tank trucks, over distances up to 200 versts (132 miles), as is for instance regularly done on the lines in the middle of Transcaucasian Asia and of Siberia, and periodically on numerous other lines, when the water in the pools and ponds becomes too hard in summer owing to drought and evaporation, or becomes frozen in winter.

The second measure consists in using four-axled tanks containing up to 25 cubic metres (5,500 English gallons) of water or more; or in adding to the ordinary three-axled tender one or two tank trucks containing up to 15 cubic metres (3,300 English gallons) of water, so as to have soft water available over sections up to 200 versts (132 miles) in length, without any need of taking in hard water at any of the stations which have only such water available.

Some of the lines feed their locomotives with pure drinking water taken from a town-supply, for instance the Warsaw-Vienna lines, the lines north west of St. Petersburg, the Zlaoust and Samara line, etc.; but the use of town water is costly. Water is softened at many stations on the Vladicaucas, on the Catherine, on the Libava-Romny, on the Nicolaiev lines, etc. The water is softened before or after it is in the locomotive.

The softening processes used are of the well-known kind, such as the Béranger and Stingel, the Desrumeaux, the Gavatson and Schlichter, etc. The reagents used are sodium hydroxide (Na HO), sodium carbonate ($Na_2 CO_3$), calcium carbonate ($Ca CO_3$), slaked lime ($Ca H_2 O_2$), etc., according to the chemical composition of the impurities contained in the water. As a rule, the reagents are first dissolved; they are then added to the water and time is allowed for settling; sometimes filters are also used; the water is then sent into the supply reservoirs. As a precaution, some of the administrations do not try to soften the water outright, but let it retain a hardness of 15 to 20 degrees (18·5 to 24·7 English degrees).

The softening of the water is sometimes completed by introducing reagents

into the tender, but this is only done to a very limited extent; this proceeding is carried out systematically only on one section (Tver) of the Nicolas line, where good results are obtained.

The western part of the Central Asia line only has water available having from 80 to 110 German degrees (99 to 136 English degrees) of hardness. This water is purified by distillation; it is evaporated in a boiler and the steam is condensed in another tank. Three stations on that line, Krasnovodsk, Djebel and Atch-Adji, use for this distillation apparatus of two kinds, the Jagn and the Tchernow apparatus.

The water obtained by this distillation has a hardness of only 2 to 5 German degrees (2·4 to 6·3 English; it gives very good results in boilers. The cost of the operation is high, and amounts to 10 rubles per cubic sagene (0·840 pence per cubic foot).

Question 2. — *State whether you are satisfied with the results obtained and, if possible, give figures shewing the saving effect in :*

1° *Fuel;*
2° *Cost of cleaning and retubing boilers;*
3° *Cost of repairs to and life of boilers;*
4° *Cost of water* (i. e. *by being able to use water which can be obtained cheaply, instead of having to purchase expensive water of better quality*).

All the administrations who go in for water purification recognize its good effects, although none of them use statistical methods for determining the saving. This is evidently because so many factore come into play, the cost of the coal, the replacement of smoke tubes, the maintenance of the boilers, etc., that it would hardly be possible to unravel matters and find out the separate influence of any one of them, such as the hardness of the water, apart from that of all the others.

Leaving figures out of consideration, the administrations attribute good results to the purification and softening of water, also as regards many other points besides coal economy, namely :

a) There is greater regularity in the train movements; sending reserve locomotives to help in the case of break-downs of other locomotives, becomes rarer and even disappears entirely;

b) Greater distances are run between two successive washings out of the boiler; washing out and scraping out the scale become easier;

c) It is found that fewer smoke tubes have to be replaced, there are fewer leaks and the tubes have to be re-expanded less frequently, and consequently the life of the tube-plates is increased;

d) The seams of the fire-box and of the boiler suffer less; there are fewer leaks at

the stays and the number of heads burnt and of fractures is reduced; the life of the boilers, of the tender tanks, of the tubes, etc., is increased.

In cases where water taken from the town supply is expensive (for instance at Baku, where that water is purified), the plan adopted is to obtain water from a soft source and convey it to the point required, and a special feed system is established, or else the available water is purified.

QUESTION 3. — *How do you deal with waters of which the hardness is mainly or largely due to calcium and magnesium sulphates, chlorides or nitrates? Do you soften such waters, and if so, what precautions do you take to prevent priming of the boilers caused by sodium salts introduced in softening?*

Hardly any instances are found on the Russian railways, of waters containing magnesium and calcium sulphates, chlorides and nitrates; if any, they are present in such insignificant proportions that they are left out of consideration.

QUESTION 4. — *Have you used barium hydroxide, barium carbonate, or barium aluminate in softening water containing sulphates. If so, please give particulars, results and cost of treatment, and state whether you find it pays.*

Barium compounds and aluminates have only been tried on three lines where there is nothing but bad water. These reagents were found to be costly and not very effective, and their use has accordingly been given up.

QUESTION 5. — *Have you made any attempt to ascertain the quantity of sodium salts present in the water of locomotive boilers when priming commences? If so, please give particulars and results of these experiments.*

Most of the railways who purify water have not had to consider this question; one only, the Vladicaucasus line, states that it has not observed that the presence of a certain excess of sodium salts in the boilers has had any particularly bad consequences.

QUESTION 6. — *Do you use, or have you used, disincrustants placed directly in the boilers, instead of treating the water before use? If so, state the nature of the materials used, and the results obtained.*

The railways who only have hard water do not use disincrustants; on the other hand those who use water of medium hardness, having a hardness of about

25 German degrees (31 English degrees), use such things as pieces or small plates of zinc hung up in the boilers, in different ways; petroleum residues are added to the water in the boiler; some railways (for instance the Nicolas line) use the Astafiew compound; one railway introduces sodium hydroxide or sodium carbonate into the boiler direct. Nearly all the lines using such processes speak favourably of them and remark that the scale in the boilers becomes less hard, and is more easily removed from the walls and stays and got rid of by washing out.

Question 7. — *In connection with water-softening or the use of disincrustants, have you been troubled with excessive leakage of boiler tubes or stays? If so, kindly give particulars, stating what you conceive to be the cause of leakage and whether any and, if so, what means you have found effectual in preventing or lessening this leakage.*

Most of the railways who use water which is comparatively soft, state that the use of disincrustants results in a reduction of leakage at the tubes; and if perchance any occurs, this is only at the start, in the case of both smoke tubes and stays.

One of the administrations who only have hard water available examined the question whether the sodium carbonate or sulphate attacked the copper ends of the smoke tubes or the copper of the tube-plates; the most delicate chemical tests did not succeed in discovering any traces of copper in the scale and in the water in the boiler, while traces of copper were detected in the residues which accumulated in the smoke-box. It was also observed on the same line, in cases where purified water was used, that leakage sometimes occurred at the smoke tubes and stays of old boilers in which there was a layer of scale, when the scale began to crack off and thus expose small surfaces not quite tight; in course of time these again became covered with scale and the leakage stopped.

Question 8. — *On what portions of the interior of the boiler do the following defects occur : 1° Cracks; 2° Pitting; 3° Grooving; 4° General surface corrosion.*

No special nomenclature has been established in Russia for describing the defects which are to be found inside locomotive boilers; the terms are used indiscriminately, and different lines apply them indifferently; no distinction is drawn between surface cracks in the metal and cracks which are sometimes found between rivet holes or extending from rivet holes to the edge of the plate; similarly linear corrosions and grooving are often confounded with fissures.

a) Surface cracks in the metal are frequently found in locomotive boilers,

whether fed with soft or with hard water; one must assume that they are the result of strains produced when the edges of the plates are sheared or perhaps when the plate is bent in two directions, for instance in making the fire-box throat plate. These strains result in minute surface cracks, invisible even when a lens is used; the water enters these cracks when the boiler is used and deposits salts in them, which when the temperature of the boiler varies help to enlarge the crack till it becomes visible.

a') The fissures which are confounded with the cracks are in all probability the result of a deformation of the metal, caused by the heating and cooling of the boiler, while under a considerable pressure. These fissures are at first very shallow, but extend over a whole section of the plate, and consequently soon penetrate.

a'') Cracks which also result from external mechanical causes, for instance in the interspaces of the tube-plates if the smoke tubes are often re-expanded, or made tight by other means than the roller expander, for instance by conical drifts; they also result from the accumulation of scale between the copper walls and the iron shell of the fire-box, if a spot not properly kept cool by the water becomes bulged by the pressure of the steam, and cracks appear.

b) Pitting which is due to the internal structure of the metal itself occurs very rarely, particularly since the progress made in the metallurgical copper and iron processes during the last ten years. This observation has been made on all the Russian lines.

c) Grooving only occurs in the surface of the iron in contact with water; it is not found in copper. The direction in which the grooving runs seems as if it were due to the existence of currents establishing themselves along the vertical iron plates; these currents avoid the stays and other obstacles and form around them eddies which corrode the walls in the immediate neighbourhood of the stays.

Such grooving is also found along seams which are not vertical, for instance near the foundation ring of the fire-box, the ring at the fire-hole, and also near the inspection holes, and in general near parts riveted to the plates and projecting on the water side. All such corrosion shows itself more quickly and becomes deeper the harder the feed-water used for the boiler. Its depth sometimes exceeds half the thickness of the plate, and if the water is hard, it already shows itself after the boiler has been in use for six to eight years; on the contrary where the water is soft (3 to 20 German degrees [3·7 to 24·7 English degrees] of hardness), no grooving is found, even in the case of boilers which have been in use for twenty-five years.

d) Corrosion in the form of pitting or of holes occurs by preference on the water side in the lower parts of the barrel of the boiler. In the case of hard water however, such pitting is also found in the steam space of the boiler and even in the walls of the steam dome; the corrosion of the walls of the iron smoke tubes must be attributed to the same cause. Corrosion of a special kind is found near the feed

pipe, if the water enters the boiler at a comparatively-low temperature. The shape of this corrosion resembles that of the water jet. Corrosion of this kind is produced even with soft water and is probably due to the periodical heating and cooling of that part of the plate. The depth and magnitude of these corrosions are only of secondary importance as compared with the grooving which in most cases makes it necessary to renew either separate plates or even the whole boiler.

Question 9. — *When the boilers undergo heavy repairs, are any notes made on the repair sheets as to the defects mentioned in question 8? Are sketches made on the sheet illustrating the actual nature, position and dimensions of these sheets chosen from amongst the most characteristic defects.*

More than three quarters of the railways who have sent answers, give descriptions and sketches of the defects observed in boilers. Only the administrations who have very pure water available for feeding the boilers, and who very rarely observe any such defects, did not do so.

The following are the figures reproduced; corresponding to the different headings :

a) Six sketches (figs. 12 to 17);
b) None;
c) Three sketches (figs. 18 to 20;
d) Four views (figs. 21 to 24) and one photograph (fig. 25).

Question 10. — *What are the methods employed in the construction of boilers to prevent any of the defects referred to in questions 8 and 9? Have modifications been carried out in the design of the boilers with this end in view? What is the breadth of the water-spaces in the fire-box? Where is the feed-water delivered, and in what manner?*

The defects of the boilers referred to under questions 8 and 9 do not hinder the service of boilers during twenty-five or even thirty-five and forty years, if maintenance and repair are well looked after; they also do not affect the actual duration of life but only the maintenance. In designing new boilers, the following principles are adopted : *a*) some of the engineers proceed to increase the thickness of the plates, both of iron and of copper; *b*) the distance between the smoke tube openings is increased, and in some cases their number is reduced, and their arrangement varied; *c*) the radii of the curves forming the corners of the plate are increased; *d*) the breadth of the water space between the fire-box walls is increased sometimes up to 120 and even 160 millimetres ($4\ ^{11}/_{16}$ and even $6\ ^{5}/_{16}$ inches);

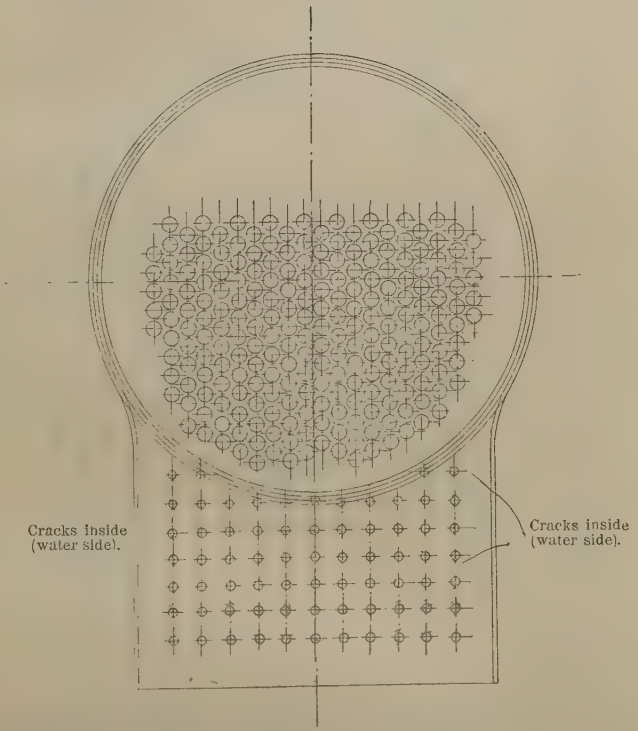


Fig. 12. — Cracks in the metal.

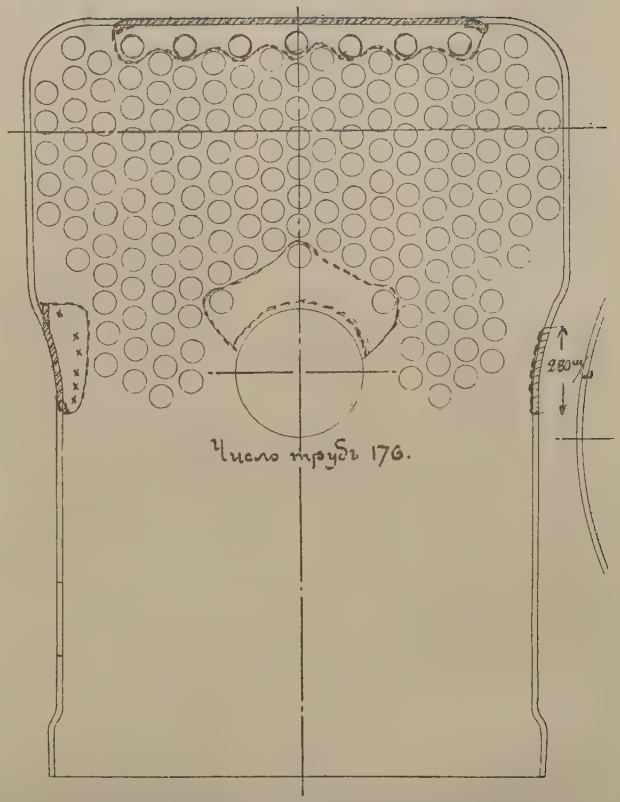


Fig. 13. — Tube-plate of fire-box. — Fissures in the metal.

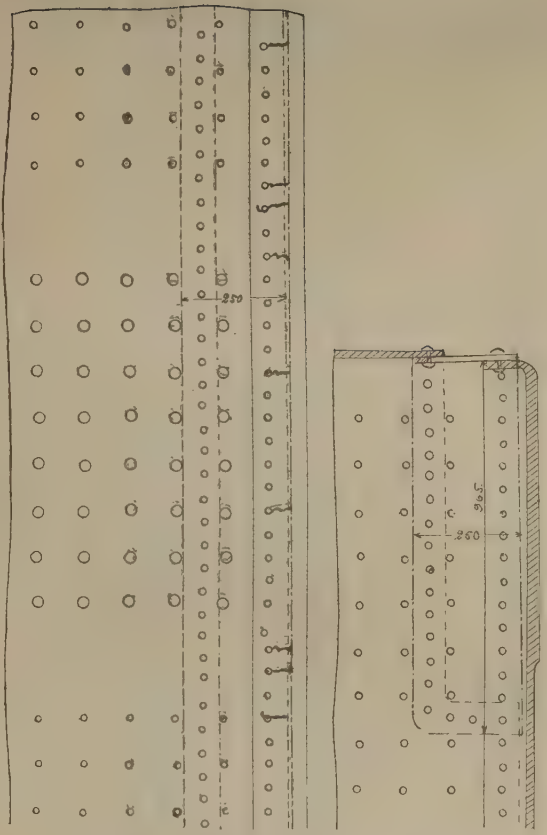
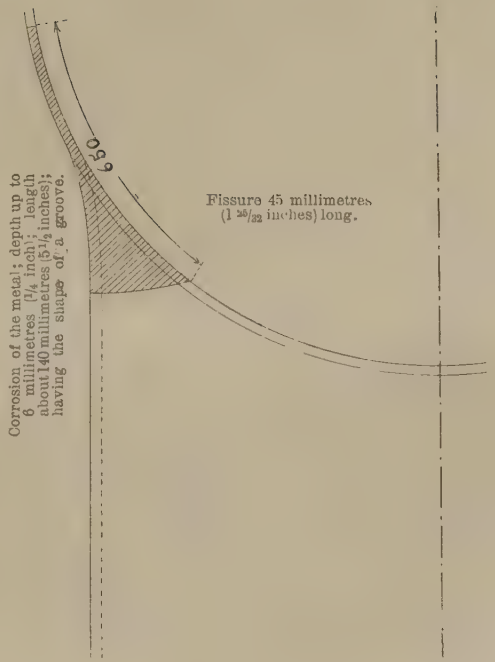


Fig. 14. — Cracks and fissures in the metal.


650
Fissure 45 millimetres (1 25/32 inches) long.
Corrosion of the metal; depth up to 6 millimetres (1/4 inch); length about 140 millimetres (5 1/2 inches); having the shape of a groove.

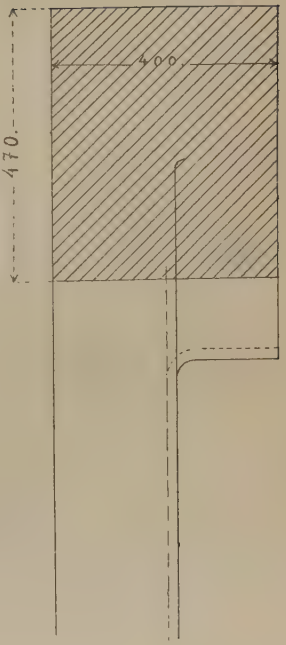


Fig. 15.

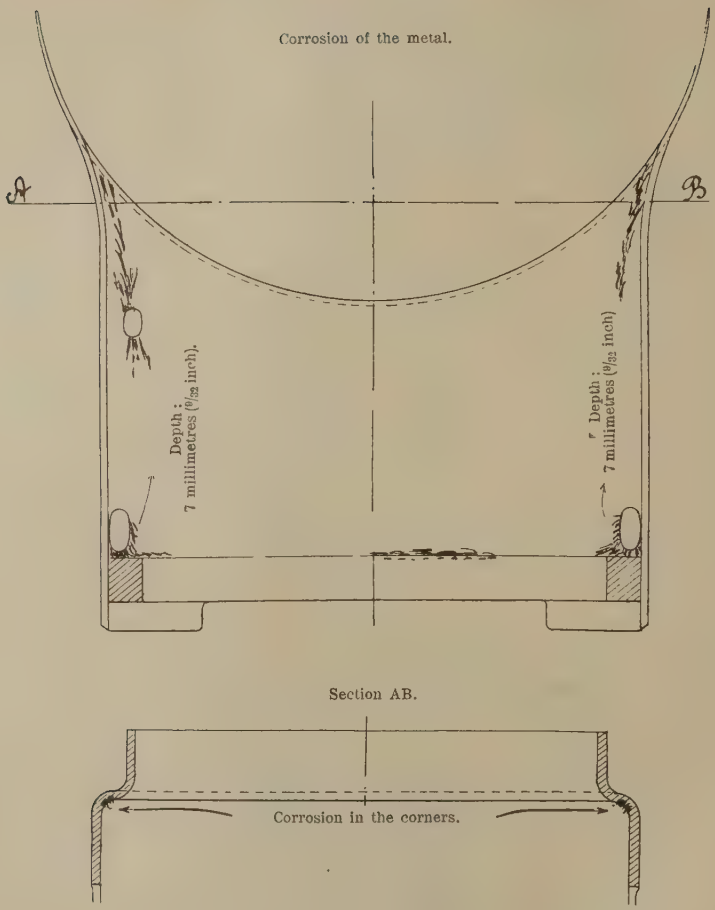


Fig. 16.

e) too great a length of fire-box (longer than 2·50 metres [8 ft. 2 3/8 in.]) is avoided, and this sometimes leads to raising the fire-box above the frame plates and increasing the width of the grate; *f*) the walls of the fire-box are stiffened by tie-rods, so as to reduce the extent of the deformation by the expansion and by the pressure of the steam; *g*) other metals are tried; for instance copper is replaced by iron.

The feed-water is by preference introduced into the boiler through long tubes arranged inside the boiler and ending at a distance of about 0·5 to 1·5 metres

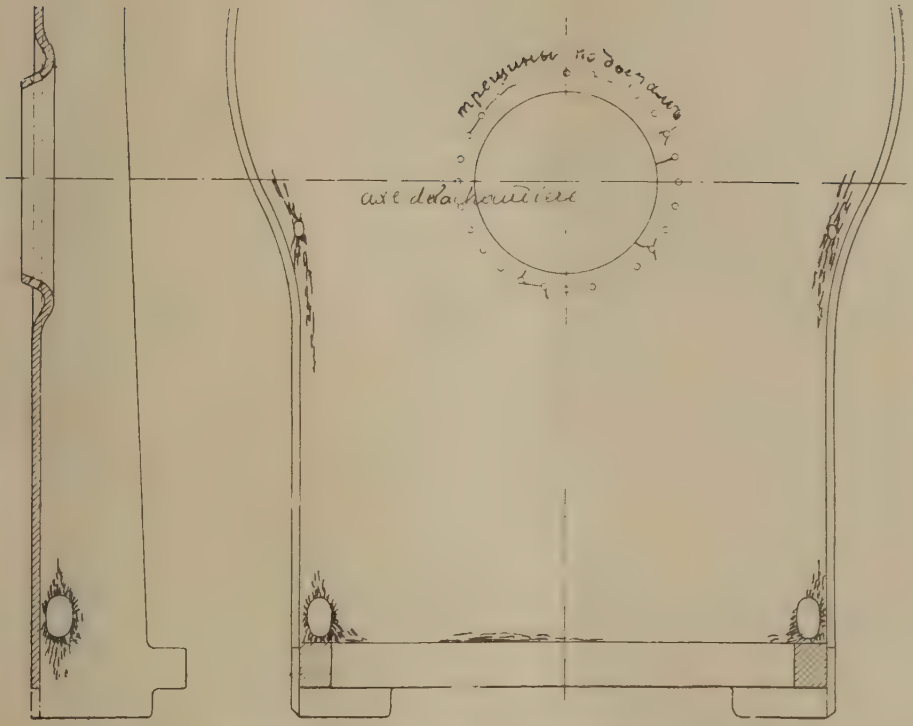


Fig. 17. — Back plate of the fire-box shell. — Cracks in the metal. — Corrosion.

(1 ft. 7 $^{11}/_{16}$ in. to 4 ft. 11 in.) from the front tube-plate, that is in the coolest part of the boiler.

Gölsdorf apparatus are being tried.

Question 11. — *Are the boilers washed out with cold or hot water? What are the mean mileages between two washings-out? In fixing these mileages, is account taken of the quality of the water? What is the time allowed for cooling down before the boiler is washed out with cold water? What pressure of water is used for washing-out? If any system of washing-out with hot water is employed, kindly describe this fully.*

All the railways without exception prefer to wash out the boilers with cold water. Hot water is used only in case of absolute necessity, if there is no time available for cooling the boiler. The distances run between two washings out vary largely with the quality of the water. When it is good, washing out takes place

Grooving, or linear corrosion.

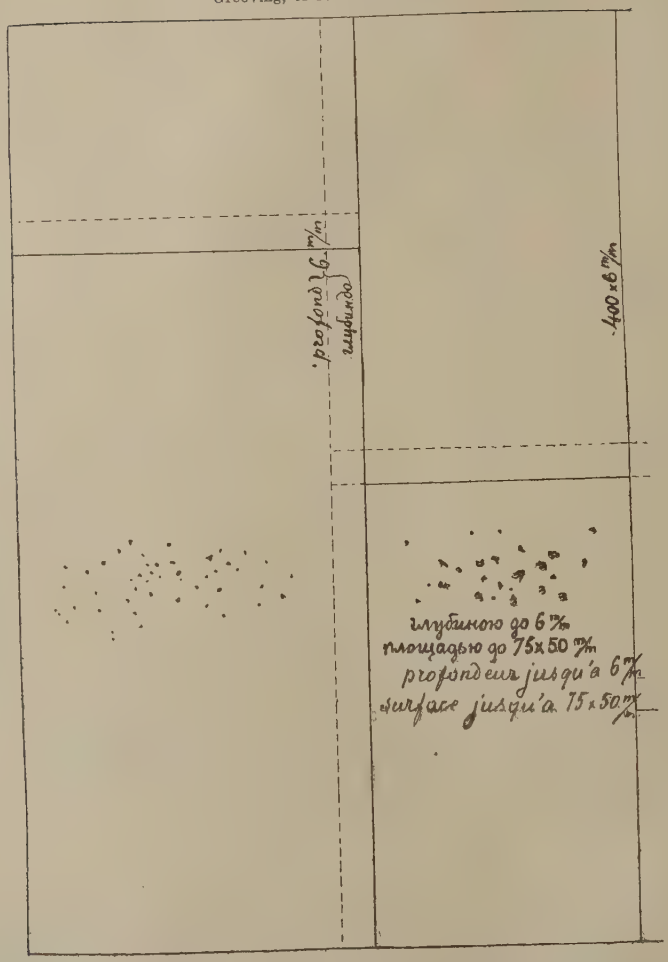


Fig. 24.
General surface corrosion.

Fig. 18.
Barrel of the boiler.

Explanation of French terms : Profondeur jusqu'à 6 millimètres. = Depth up to 6 millimetres (1/4 inch).
Surface jusqu'à 75 × 50 millimètres. = Area up to 75 × 50 millimetres (2 15/16 × 1 31/32 inches).

after running 1,500 to 2,500 versts (1,000 to 1,660 miles); when water is bad, it may be necessary to do this after 500 versts (330 miles), but this figure is very rare. As a rule the distance is 800 versts (530 miles) in busy times.

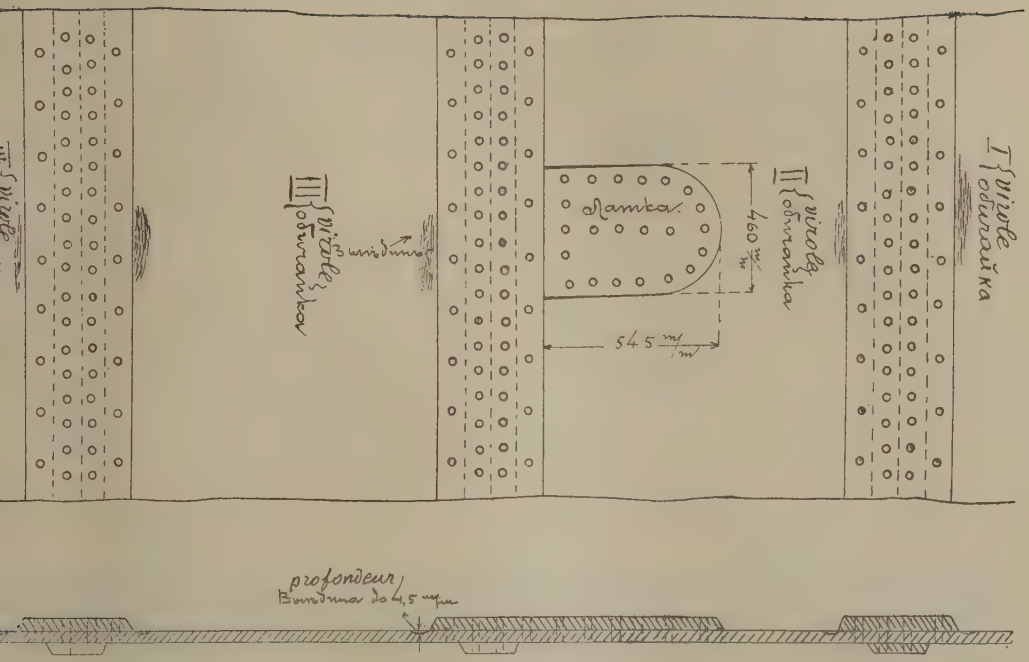


Fig. 19. — Grooving.
Explanation of the French term : Profondeur = Depth.

The boilers of shunting locomotives are washed out once or twice per month. In order to let the boiler cool before washing it out, twelve to forty-eight hours are allowed, according to the needs of the locomotive department; hot water is only used (for instance by means of an injector) in extreme cases, such as in side eight hours after the locomotive has been uncoupled. The different railways who have tried washing out with hot water consider that local conditions may make this process advantageous, and that it does not hurt the preservation of the boiler. The water is heated either in the tenders or in special tanks made of concrete.

No case is reported of any cracks having been formed in the plates during washing out. We only know of two cases of the formation of cracks in the fire-box plates of the Baldwin locomotives built in 1874. These plates were made of ingot iron and became cracked over a whole section, near the middle, while the boiler was cooling before the washing out. The water used for washing out boilers is either under a pressure of $^3/_4$ to 1 $^1/_2$ atmospheres (11 to 22 lb. per square inch), due to the head of water, or under a pressure which reaches 6 atmospheres (88 lb. per square inch) when special pumps are used. The latter pressure is used more especially where the water is hard and gives very adherent scale.

1165
955

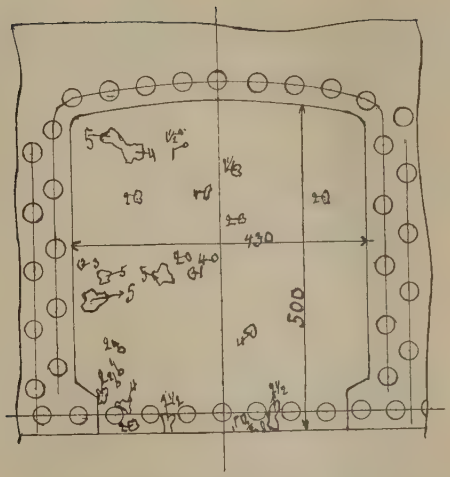


Fig. 23. — Corrosion.

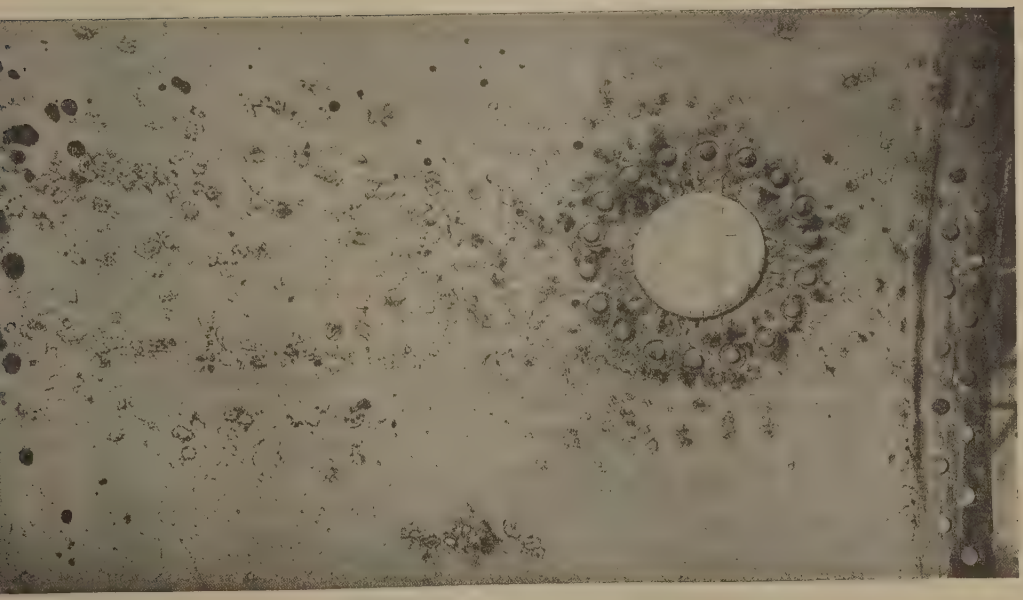


Fig. 25. — General surface corrosion.

QUESTION 12. — *Is blowing off a portion of the water under pressure resorted to in order to prevent the formation of deposit and to check priming? If this practice is carried out, at what time and after what intervals is it done? What means are adopted to remove the water? Shew by sketches the position of the blow-off cock and its design.*

Blowing off under pressure is a practice only adopted on about half the railways who have sent us answers, and only on railways where the water is hard.

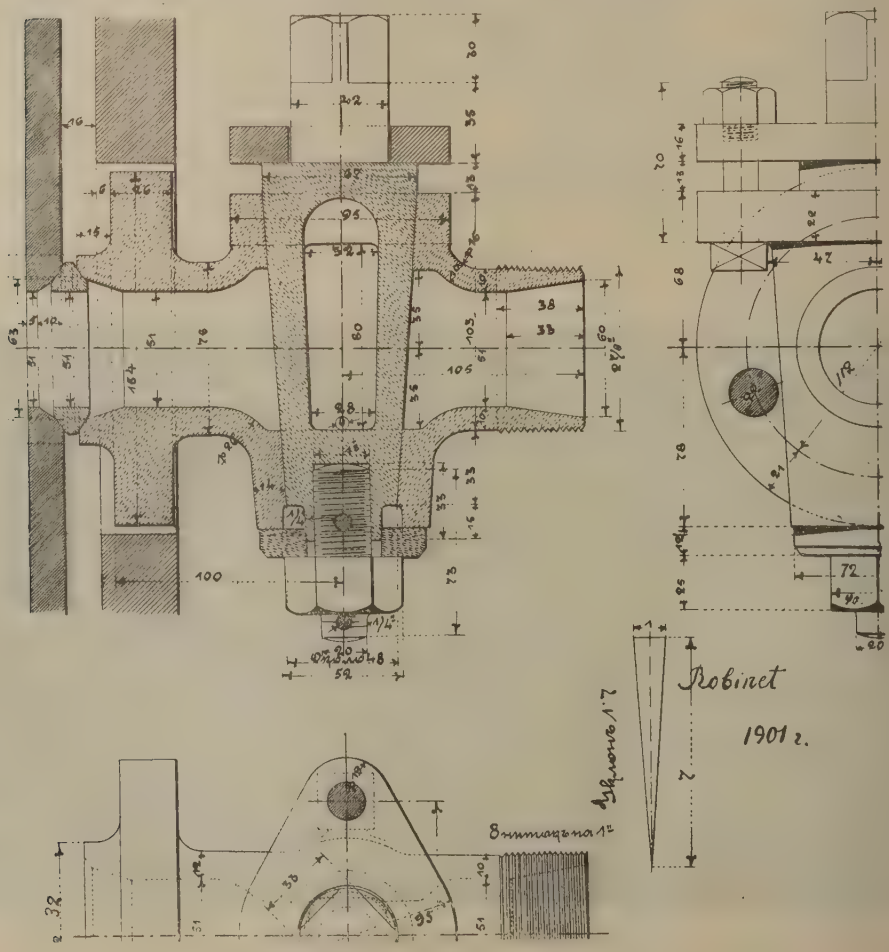


Fig. 26. — Blow-off cock, 1901.

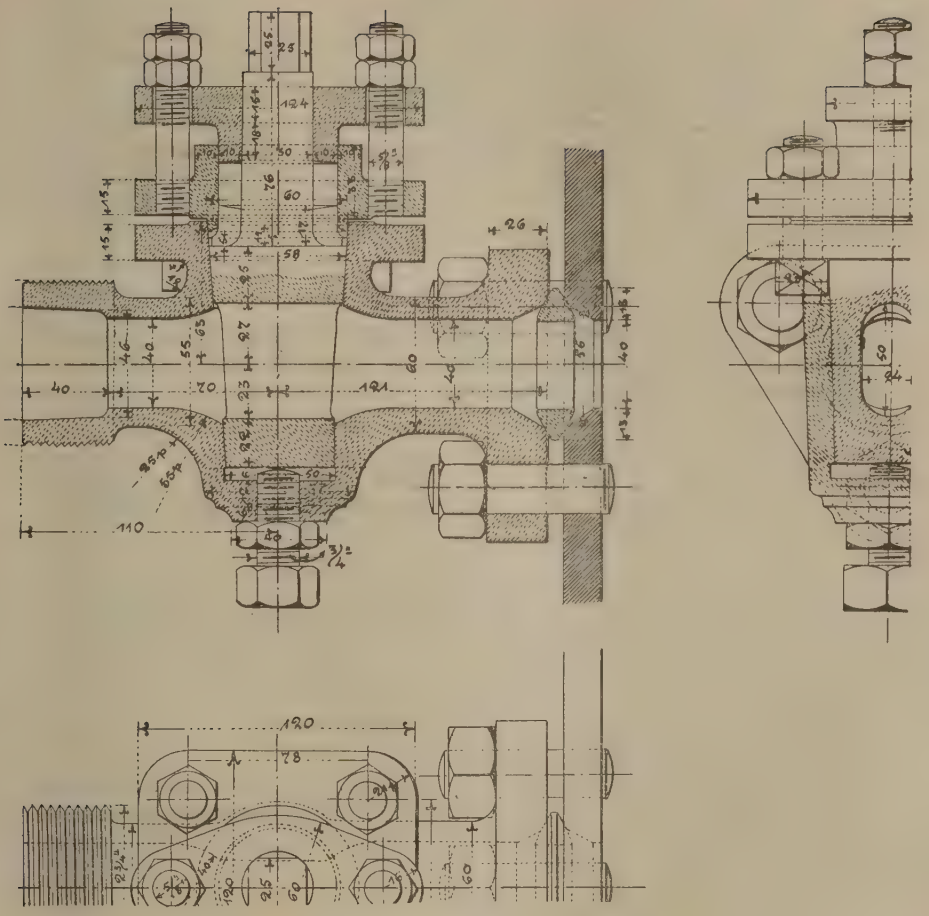


Fig. 27. — Blow-off cock, 1903.

The *modus operandi* varies more. Some of the railways leave this work to the driver, others specify that it is to take place after the work of the locomotive is finished and it has arrived at its depot or at the chief depot, once or twice between every two washings out. The way in which the water is drawn off before the washing out depends on the washing-out process adopted. Before washing out with cold water, the inspection holes are opened and the steam is allowed to escape; the water in the boiler then gradually cools down to 30 or 40° (86 to 104° Fahr.), and after it has become cooled, it is allowed to run out through the fire-box plugs;

finally the boiler is washed out. When hot water is used for washing out, the water from the boiler is run out and the boiler is allowed to cool to 80 or 90° (176 or 194° Fahr.) and the washing out is then proceeded with.

The blow-off cock is generally fixed to the bottom of the fire-box at a distance of 130 millimetres (5 1/8 inches) from the foundation ring on one of the four walls of the fire-box. Sometimes two blow-off cocks are fitted on two opposite sides.

Two blow-off cocks No. 15 are shown in figures 26 and 27.

Question 13. — *If you have any waters which are specially corrosive to boilers, but which by analysis are not found to contain free mineral acid, please give analyses stated in parts per 100,000 shewing if possible) the amounts of*

Lime (*Ca O*);
Magnesia (*Mg O*);
Soda (Na_2 *O*);
Alkalinity (*as Ca* CO_3);
Sulphuric anhydride (SO_3);
Nitric anhydride (N_2 O_5);
Chlorine (*Cl*);
Carbon Dioxide (CO_2), *free*
Total Solid Matter at 130° C. (*266° Fahr.*)

The answers received from the different administrations unfortunately give no information as to the temperature at which the residue was dried before analysis, with the exception of the Perm line, which states that the residues, dried at 130° C. (266° Fahr.), obtained by evaporation amounted to 0·483, 0·310, 0·371 and 0·522 gram per litre (34, 22, 26 and 37 grains per English gallon) respectively, at the four stations named in the annexed table.

In the answer to question 1 it was already stated that the greatest hardness amounted, in certain instances, to 92 German or 117 English degrees of hardness.

The annexed table gives instances of the analysis of water of various hardness, used on different railway systems.

Question 14. — *Have you tried to prevent corrosion by coating the insides of boilers with Portland cement or any kind of paint, or by treating the water with a definite excess of lime or other chemical to neutralise carbonic or other acid, or by introducing chemicals or other substances into the boilers? If so, please give full particulars and results.*

Most of the railways have made no attempts to paint or coat the inside of boilers. Some send the following information :

a) The Vladicaucasus line states that it has used for the purpose tar and cement, and has even tried tinning, but no useful result was obtained.

LINE.	STATION.	Source of origin.	Calcium oxide Ca O.	Magnesium oxide Mg O.	Carbonic anhydride CO_2.	Sulphuric anhydride SO_3.	Chlorine Cl.	Hardness.		*Remarks on the use of the water.*
								German degrees.	English degrees.	
Vladicaucasus . . .	Kayala	Well.	0·2888	0·2700	0·1298	1·266	0·0603	68°	84·4°	Purified.
	Kustchevka . .	...	0·5800	0·2420	0·1760	1·97863	0·2201	92°	115°	—
	Sossika	River.	0·2910	0·2379	0·1870	1·114	0·0886	62°	78·2°	—
	Tikhorietskaya . . .	River (in winter).	0·2700	0·3639	0·1562	1·8802	0·1490	78·8°	98·2°	— —
	Bièloglioskaya . .	Well.	0·205	0·0540	0·1034	0·2210	0·0568	28·1°	35°	Not purified.
Catherine	Grichino	Pond.	0·2615	0·1445	...	0·8745	0·1242	...	57·8°	Not purified.
	Pologui	Artesian well.	0·4755	0·0953	. .	0·4073	0·4899	...	76°	—
	Jousovo.	...	0·2210	0·1334	. .	0·6955	0·3337	...	51°	Purified.
Transbaïkal . .	Tchita (atelier central).	...	0·0686	traces	0·2860	0·0118	0·0053	0·47°	...	Not purified.
	Sakhudo	...	0·0285	0·0072	0·0510	néant	néant	2·29°	...	— —
	Bouriatskaya . . .	Well.	0·1656	0·0546	0·1330	0·0531	0·0071	4·55°	...	— —
	Kouenga	...	Nil.	Nil.	Nil.	0·0027	Nil.	1·75°	...	—
Moscow-Kursk . .	....	. .	.....	The hardest waters have 7 to 8°						Not purified.
Perm.	Poklevskaya . . .	.	0·140	0·021	...	0·042	0·031	16.0°	...	Not purified.
	Luza.	.	0·020	0·015	...	0·009	0·008	4·2°	...	— —
	Rudiauka	. .	0·020	0·018	...	0·016	0·029	4·5°	...	— —
	Lundauka	...	0·075	0·021	...	0·041	0·028	10·4°	...	— —

b) The Nicolas line (Moscow-St. Petersburg) has used red-lead paint and has found it to be of some use.

c) The Perm line and the Samara-Zlatoust line have tried filling up pitting and grooving, inside the boiler, with tin or with babbit; this filling holds well, does not become modified and does not work loose from one general overhaul to the next. A soldering iron is used for the tinning.

Question 15. — *Do you use zinc plates in your boilers? If so, explain, with sketches, the method of application and the results as regards*

1° *Prevention of incrustation;*

2° *Prevention of pitting and corrosion.*

Only three railway systems sent information about the results of experiments made with zinc plates suspended inside locomotive boilers. All three gave up these experiments as no good results were obtained The zinc was introduced in pieces or in plates, in quantities of 10 pounds at least for a run of 100 versts (66 miles).

Question 16. — *What metal or alloy is used or has been tried for fire-box stays; if any metal other than copper or iron, give composition. What advantages have been found to result from the use of these other metals or alloys? Is any trouble experienced with stays breaking; if so, please state where these fracture occur and indicate :*

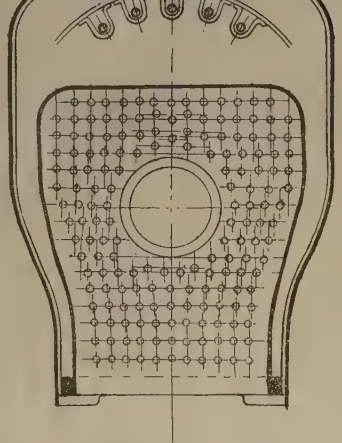
1° *The position in the stay itself;*

3° *The position of the stays in the box.*

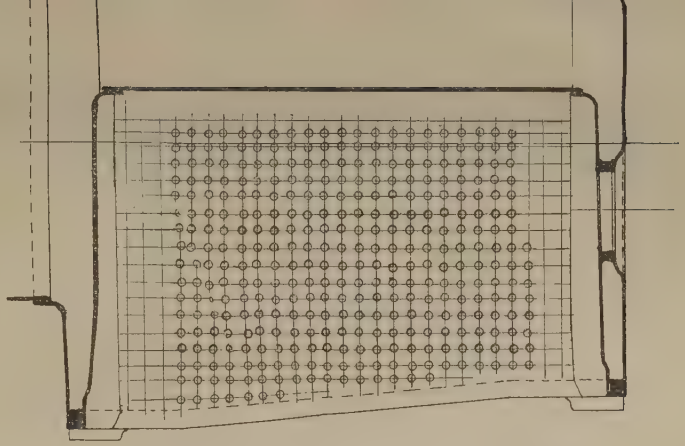
Are any special means adopted to detect fractures? Is any type of flexible stay used? Are you troubled with stay heads burning away and dropping off in the fire-box? If so, what means have been adopted or tried to prevent this, and with what result?

The Russian railways make the boiler stays of copper or of iron. The stays of one and the same fire-box are either all iron, or all copper, or partly of each. Certain lines use iron stays at places where they are in immediate contact with the coal; others use iron for stays at those points where fractures of stays occur; finally the administrations which use pressures going to 14 atmospheres (206 lb. per square inch) propose to use copper for the stays. Two lines, the Sizran-Viasma and the Central Asia, on which the diameters of the stays become very large in consequence of frequent replacemant, use copper exclusively when the diameter is 36 millimetres (1 $^{13}/_{32}$ inches) or more.

No other metals or alloys are used, besides iron or copper; it is only quite recently that a trial of silicon bronze has been begun, at the suggestion of a Russian locomotive builder; up to the present no information is available as to results.

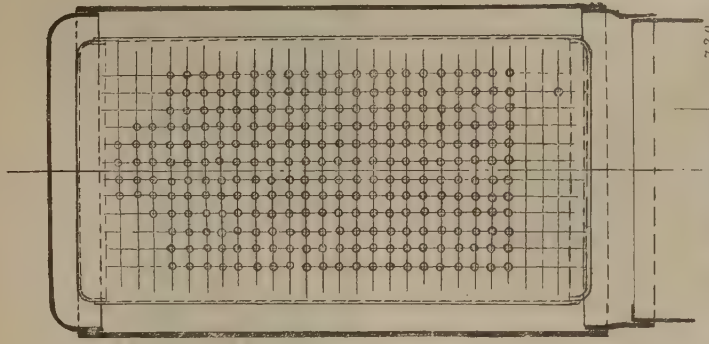


Cross-section
and view of back plate of fire-box.

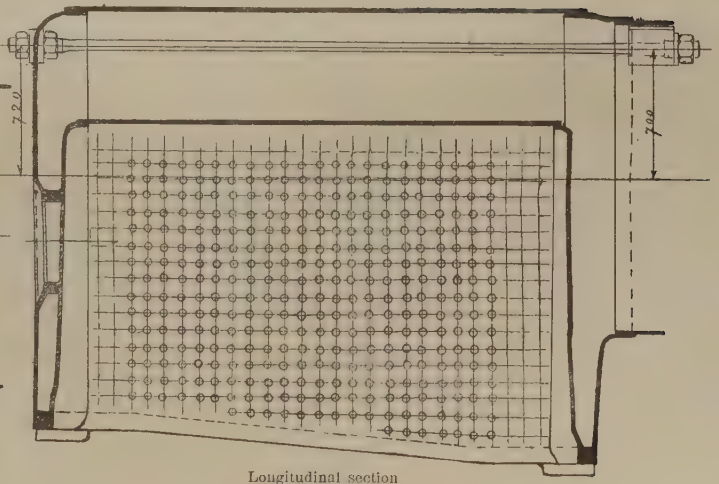


Longitudinal section and view of right side of fire box.

Fig. 28.



View of fire-box crown (from above).



Longitudinal section
and view of left side of fire-box.

Fig. 29.

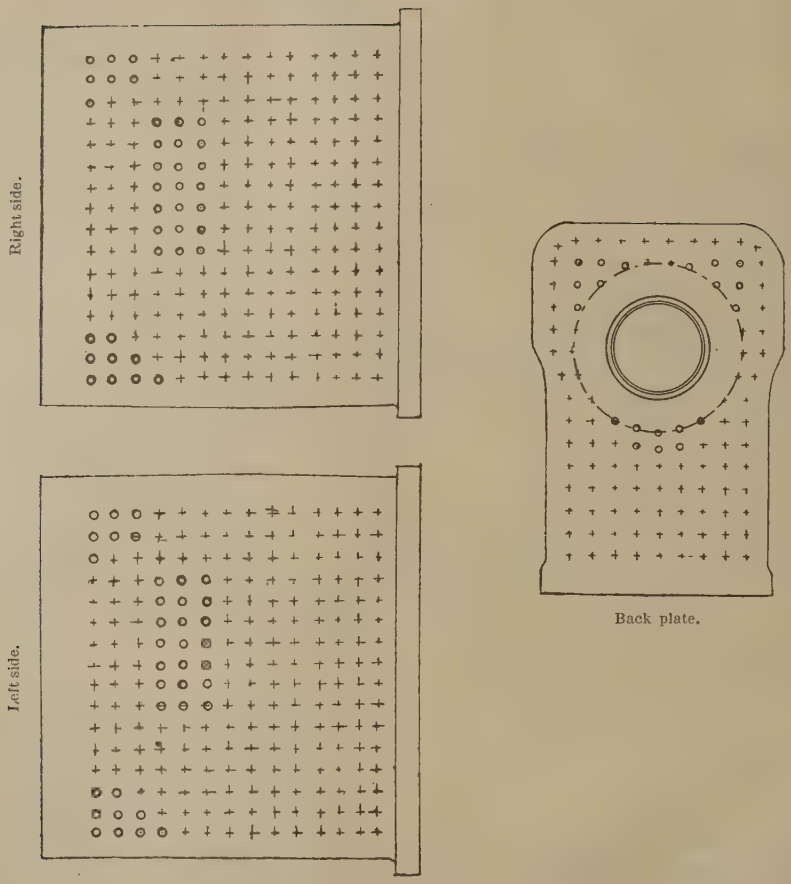


Fig. 30. — Fire-box shell.

Fractures of stays have been observed, but they occur at very varying places.

a) As regards the stay itself, most of the railways state that fractures occur near the fire-box shell. The Vladicaucasus, the Catherine and the North Western lines alone state that the fractures occur by preference at the points of contact with the copper plate; two former railways have bad water and the last very good water.

b) As regards the parts of the fire-box and the positions in the plates, where fractures occur most frequently, most of the railways state that these fractures occur most frequetly near the bends of the plates and near the vertical corners. Some of

the peculiarities of the distribution of the fractures are shown in figures 28 to 30, as observed on the Vladicaucasus and Central Asia lines. As the Russian railway administrations, in the large majority of cases, have very pure water available, they are not led to study this question as much as the administrations in other countries.

In order to detect broken stays, small holes are drilled or punched in from each end to a depth of 35 millimetres (1 3/8 inches), measured from the surface of the head. These holes, which are 2·5 or 3 millimetres (3/32 or 1/8 inch) in diameter, facilitate the detection of broken stays.

Flexible stays are not used.

Cases of stay heads burning away and dropping off are occasionally observed. The number of such cases was materially reduced when the thickness of the heads, formerly 12 millimetres (15/32 inch), was reduced to 7 millimetres (9/32 inch); the head is then sufficiently cooled and owing to its smaller bulk, it does not become red hot and burns away less, even if coal containing sulphur is used for firing.

QUESTION 17. — *Have you tried lining the fire-box or any part of it with firebricks or fireclay slabs to protect the stays from the action of the fire and to promote better circulation of the water in the fire-box; if so, give results, and state the nature and composition of fire-resisting material used.*

The walls of the fire-boxes of the Russian locomotives are lined with firebricks or fireclay for two reasons : if petroleum is used for firing, in order to protect the walls against the excessive temperature of the petroleum flames; if coal is used for firing, in order to protect the heads of the copper stays against the action of the sulphur. In either case the thickness of the firebrick or fireclay lining varies between 2 and 3·5 centimetres (between 13/16 inch and 1 3/8 inches).

The refractory materials used are of local origin. The protection of the walls of the fire-box by such a refractory lining certainly attains its object when petroleum is used for firing; when coal is used for firing, it is also considered advantageous by the railways who go in for this practice. When wood is used for firing, the walls have no protective lining.

CONCLUSIONS.

A very large majority of the Russian railways have good water available for feeding the boilers, which is nearly absolutely pure, and does not affect the wear of the boilers, even in twenty-five years of use; consequently many of the railways do not occupy themselves with keeping statistics relating to the influence of the water on the life of the boilers.

*

A minority of the railways have only hard water available and consequently (as compared with the railways just mentioned) have been quick to ascertain the injurious effect of such water; these railways have tried the frequent washing out of boilers, and the purification of the water, in order to prevent damage to the boilers or at least to reduce it. The chemical processes of purification have proved that it is necessary to avoid the presence of an excess of soda in the purified water; and consequently many of the railways only effect a partial purification of the water by means of soda.

At three of the stations on the Central Asia line, the very hard water is purified by distillation.

Purification of the water by means of zinc, barium salts, Campeachy wood, petroleum residues, etc., has only been tried in a few exceptional cases.

Boilers are washed out, either with hot or with cold water, after running 500 to 800 versts (330 to 530 miles), on some lines where only hard water is available.

Blowing off the boilers under pressure is not a general practice.

Hard water has a great influence on the corrosion of the boilers and on the regularity of the train service. The residues left on evaporating hard water which are in the form of scale, attack the iron walls of the boilers immediately, probably by a chemical action; on the other hand the walls made of copper, which are subjected to the immediate action of the fuel, have a greater tendency to burn away in consequence of the reduced conductivity produced by the adherent scale.

These two cases result in damage of different kinds, namely: in the case of iron walls, in corrosion, cracks and grooving, rarely fissures; in the case of copper, on the other hand, in fissures, cracks and in burning away, according to the thickness.

The places where damage occurs are those which are subjected to repeated bending from the periodical heating and cooling of points where scale can collect without difficulty; for instance the lower part of the barrel, that of the fire-box and the crown of the latter.

As protection against such damage, the following may be mentioned: stiffening the walls of the boiler so as to reduce the amplitude of the flexure when heating up; the use of mud pockets for the residues obtained by the evaporation; as well as a design of boiler which makes it easier to scrape and wash out the scale, and prevents the deposit of the latter.

As regards stays, the Russian railways have not as yet been led to consider the use either of a complex shape (flexible stays) or of materials other than iron and copper.

[621 .133.3 & 621 .134.3]

REPORT N° 3

(France, Belgium, Italy, Spain and Portugal)

By C. DASSESSE,

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Steam superheaters and distribution of superheated steam.

GENERAL TECHNICAL CONSIDERATIONS.

The savings in coal and water effected by superheating result essentially from the increase in the volume of the steam under constant pressure, from the reduction or elimination of condensation in the cylinders and from the evaporation of the water carried over into the superheater elements.

Saving due to the increase in the volume. — Let

t the temperature of the saturated steam;
t' the temperature of the superheated steam;
t_0 the temperature of the feed-water;
v the volume of one kilogram of saturated steam at the temperature t;
v' the volume of one kilogram of superheated steam at the temperature t';
Q the number of calories contained in one kilogram of saturated steam at the temperature t;
Q' the number of calories contained in one kilogram of superheated steam at the temperature t';
c the specific heat of the superheated steam; $c = 0{\cdot}54$.

*

We have :

$$Q = 606{\cdot}5 + 0{\cdot}305t;$$
$$Q' = 606{\cdot}5 + 0{\cdot}305t + 0{\cdot}54\,(t' - t).$$

On the other hand, we have :

$$Q = 476{\cdot}11 + 4Apv;$$
$$Q' = 476{\cdot}11 + 4Apv',$$

where p is the pressure of the steam in kilograms per square centimetre and A the mechanical equivalent of heat $= \frac{1}{425}$.

Hence we obtain :

$$\frac{v'}{v} = \frac{Q' - 476{\cdot}11}{Q - 476{\cdot}11}.$$

If P and P′ represent the weights of water respectively consumed by a locomotive without superheating and by one with superheating, hauling a train under the same conditions of weight, profile and speed, then, assuming a constant volume of steam per unit of work, we have :

$$Pv = P'v',$$
$$\frac{P'}{P} = \frac{v}{v'} = \frac{Q - 476{\cdot}11}{Q' - 476{\cdot}11}.$$

Now $\frac{P'}{P}$ gives the economy of water resulting from the superheating.

For instance : let $p = 13$ kilograms per square centimetre, $t = 190°$ C, $t' = 250°$ C.

$$Q = 606{\cdot}5 + 0{\cdot}305 \times 190 = 664 \text{ calories.}$$
$$Q' = 606{\cdot}5 + 0{\cdot}305 \times 190 + 0{\cdot}54\,(250 - 190) = 696 \text{ calories.}$$
$$\frac{P'}{P} = \frac{(664 - 476)\,100}{696 - 476} = 85{\cdot}5 \text{ per cent.}$$

The locomotive using superheated steam will only consume 85·5 per cent of what the locomotive using saturated steam uses; thus the saving in water will be 14·5 per cent.

As regards the saving in coal, this depends on the ratio between the quantities of heat contained respectively in 0·855 kilogram of superheated and 1 kilogram of saturated steam, that is on the expression :

$$0{\cdot}855\,\frac{(Q' - t_0)\,100}{Q - t_0} = 0{\cdot}855\,\frac{(686 - 10)\,100}{664 - 10} = 90 \text{ per cent.}$$

t_0 being equal t_0 10°.

In other words, the superheated-steam locomotive consumes about nine tenths of what the other consumes; the saving is thus 10 per cent.

Mr. Strahl, of the Prussian State Railway, gives in the table reproduced below, the saving in water and coal which results from the increase of volume with different amounts of superheat, the boiler pressure being 13 kilograms per square centimetre (184·90 lb. per square inch).

Temperature of superheated steam.	Saving, per cent.		Temperature of superheated steam.	Saving, per cent.	
	Water.	Coal.		Water.	Coal.
200° C.	2·5	2	260° C.	16	12
210° C.	5	2·5	270° C.	18·5	13
220° C.	8	5	280° C.	20·5	14·5
230° C.	10	7	290° C.	22	16
240° C.	12·5	9	300° C.	24	17
250° C.	14·5	10	350° C.	34	24

As we see, the saving increases with the amount of superheat.

A similar calculation made for pressures of 11, 9 and 7 kilograms per square centimetre (156·45, 128 and 99·56 lb. per square inch), with steam superheated to 300° C. (572° Fahr.), gives the following results :

Steam pressure.	Temperature of the superheated steam.	Temperature of the satured steam.	Amount of superheat.	Saving, per cent.	
				Water.	Coal.
13 kilog. per square centimetre .	190·57° C.	300° C.	109·43° C.	24	17
11 — —	183·05° C.	300° C.	116·95° C.	25·5	18
9 — —	174·38° C.	300° C.	125·62° C.	27	19·5
7 — —	164·03° C.	300° C.	135·97° C.	29	21

It follows from this table that the highest superheat, that is that obtained at the lowest steam pressure, corresponds with the greatest saving in water and in coal, and this gives us a preliminary indication that as a rule, when using superheated steam, it is not of interest to have a high pressure at admission.

The two tables just given are based on an equal consumption of volume of steam, whether saturated or superheated, for the same amount of work ; but if, as Mr. Garbe has done in his investigation of modern locomotives, we determine the theoretical work obtainable from 1 kilogram (2·2 lb.) of saturated steam and from 1 kilogram

(2·2 lb.) of superheated steam at 300° (572° Fahr.) taking in each case as basis the adiabatic expansion, and if we determine subsequently the weight of steam used per horsepower-hour and the corresponding number of calories, we find for the saving in water and in coal the following figures (*cp* being equal to 0·48) :

Steam pressure.	Temperature of superheated steam.	Theoretical saving, per cent.	
		Water.	Coal.
13 kilograms per square centimetre.	300° C.	10·99	3·95
11 — — —	300° C.	13·33	6·13
9 — — —	300° C.	14·96	7·21
7 — — —	300° C.	16·75	8·56

Saving due to the reduction or elimination of condensation. — When the steam coming from the boiler arrives in the cylinders, it comes into contact with walls which have been cooled by the expanded steam; as it is a good conductor of heat, it condenses in part, giving up its latent heat which passes into the metal of the cylinder. Towards the end of the expansion and particularly at the beginning of the exhaust, the condensed water is re-evaporated by the heat given up by the walls of the cylinder, which have then attained a higher temperature than the exhaust steam, and this heat taken up again from the cylinder escapes into the outer air as a loss pure and simple.

The amount of this condensation varies with the working pressure, the extent of the cooling surfaces and the degree of expansion; it may amount to 50 per cent of the total weight of steam coming out of the boiler.

By heating the saturated steam sufficiently in a superheater which communicates with the boiler which is kept at a constant pressure, we make of it, to some extent, a perfect gas which has the property of being a bad conductor of heat and making more difficult exchanges of heat between the steam and the cylinders.

This property is not really obtained unless the steam no longer contains particles of liquid, for the latter not only cool the superheated particles, but their conductivity also contributes to the cooling of the mixture. According to Mr. Garbe, an appreciable economy only begins to make itself felt when there is at least 50° C. (90° Fahr.) of superheat, and then increases rapidly; it is necessary that the mean temperature in the valve chest amounts to 300° C. (572° Fahr.) in order that the superheated steam may be homogeneous, that is to say no longer contain liquid or saturated particles, and beyond 320° C. (608° Fahr.) all condensation, even in a single-expansion engine, is eliminated.

The heat absorbed by the walls of the cylinders is then supplied by a lowering of

the temperature of the steam instead of being supplied by its condensation. If the steam is strongly superheated, there may even be superheat left in the exhaust steam, but even in that case, the exchanges of heat which go on at each cycle between the steam and the cylinders are very much smaller that if saturated or insufficiently-superheated steam were in question, capable of becoming condensed during the cycle : the mean temperature of the steam remains higher. Hence a saving, called the saving due to the temperature, results from the fact that the steam has been superheated to such a degree that it can cool without becoming condensed.

During the trials made by Mr. Schmidt, it was found that for each per cent of steam condensed at the end of admission, in the case of saturated steam, the steam introduced must be superheated 4° C. (7·2° Fahr.) in order to avoid any condensation at that point. If 25 per cent of the saturated steam condenses during admission, 100° C. (180° Fahr.) of superheat would be required to keep it dry. If we assume that each cylinder full means 1 kilogram (2·2 lb.) of steam, the total admission would have been, with 25 per cent of condensation, $\frac{1}{0{\cdot}75} = \frac{4}{3}$ kilograms (2·94 lb.); now as each kilogram (2·2 lb.) of steam at a pressure of 13 kilograms per square centimetre (184·90 lb. per square inch) requires 664 calories (2,635 British thermal units) for its generation, the conversion into steam of $\frac{4}{3}$ kilograms (2·94 lb.) of water will require $\frac{664 \times 4}{3} = 885$ calories (3,512 British thermal units). If the steam is superheated by 100° C. (180° Fahr.), 1 kilogram will require only $664 + (0{\cdot}54 \times 100) = 718$ calories (2,849 British thermal units per lb.), whence an economy of $\frac{(885 - 718)\ 100}{885} = 18{\cdot}9$ per cent arising from the fact that the temperature of the steam is sufficiently high to be able to cool without condensation.

As corrections to the preceding, we must take into account : 1° that internal losses are only reduced and not eliminated by superheating; 2° that superheat may still be present at the moment of exhausting; 3° that the superheater does not utilize heat so well as the boiler; the gases which enter the superheater tubes leave it at a higher temperature than those leaving the smoke tubes; this forms a loss in the efficiency of the boiler, and this loss increases with the amount of the superheating, owing to the higher temperature of the steam to which the heat has to be transmitted; 4° that with saturated steam part of the condensed saturated steam re-evaporates during the expansion and does work : for the same cut-off, the final pressure of superheated steam is less than that of saturated steam; 5° that not only is strongly-superheated steam a bad conductor of heat, but it is fluid like a gas and this double property has an advantageous influence on the period of admission to the cylinders, as is shown by the indicator diagrams taken and the experiments recently made on the Belgian State Railway, and described in a note attached to

this report. The pressure at admission is higher than with saturated steam and the efficiency of the engine is accordingly increased.

Dimensions of the cylinders of superheated steam locomotives. — The addition of a superheater is equivalent to an indirect increase in the power of the boiler as the weight of steam consumed is reduced. The consequence is that the power of locomotives can be increased without having to give excessive dimensions to the boilers.

In order to utilize the increased power of the boiler, it is advisable to keep to the same cut-off and degree of expansion and to increase the diameter of the cylinder. In this way, one avoids the losses resulting from incomplete expansion as well as greater back-pressures on the pistons.

Let us remember that the volume v of a kilogram (2·2 lb.) of saturated steam has expanded during its passage through the superheater and has become equal to $v\,\frac{Q' - 476}{Q - 476}$; this kilogram of superheated steam contains $(Q' - q_0)$ calories, while the kilogram of saturated steam only contains $(Q - q_0)$. For an equal weight of coal burnt on the grate, the volume of superheated steam supplied is

$$v' = v\,\frac{Q' - 476}{Q - 476} \times \frac{Q - q_0}{Q' - q_0}.$$

When $p = 13$ kilograms per square centimetre and $t' = 300°$ C., we obtain

$$\frac{v'}{v} = 1{\cdot}21 \quad \text{et} \quad \frac{d'}{d} = 1{\cdot}1.$$

If in addition we allow for a condensation of 20 per cent in the cylinders, the formula becomes

$$\frac{v'}{v} = \frac{Q' - 476}{Q - 476} \times \frac{5}{4} \times \frac{Q - q_0}{Q' - q_0},$$

$$\frac{v'}{v} = 1{\cdot}51 \quad \text{and} \quad \frac{d'}{d} = 1{\cdot}22.$$

This formula gives too high values for d' as it neglects the internal losses of superheated steam, the possible superheat in the exhaust steam, the less good utilization of the heat by the superheater and the re-evaporation of the condensed water during the expansion of the saturated steam.

It is very important that the steam should be very dry before it enters the superheater. In fact, 540 calories (2,143 British thermal units) are required for evaporating 1 kilogram (2·2 lb.) of water, and 54 calories (214 British thermal units) are required to raise its temperature to 100° C. (180° Fahr.) above that of saturated steam; 1 per cent of water entering the superheater makes the superheat drop 10° C. (18° Fahr.) apart from the more or less quick deposit of scale which may result.

Single expansion with superheat and compound with saturated steam. — As superheating materially increases the volume of the steam and eliminates condensation, a larger quantity of steam is available and the engine can do more work. This result is obtained without increasing the working pressure and without any alterations except the addition of the superheater and the increase af diameter of the cylinders. Hence it is possible to keep to single-expansion locomotives of the existing dimensions and all the other advantages inherent in that system, such as simplicity of construction, easy driving, reliability, adaptability to all services, moderate working pressure of the boiler, etc.

As regards the question whether, when superheated steam is utilized, the 2-cylinder or the 4-cylinder non-compound type is to be preferred, Mr. Schmidt states that for high-speed locomotives the first design has some defects, principally owing to the unequal pressures of the steam and of the masses preventing smooth running. In such cases, four cylinders are to be preferred.

As with superheating, compounding also has the effect of reducing condensation by reducing the drop of temperature in the cylinders. With double expansion, the steam condensed at admission into the small cylinder evaporates, at all events in part, during the exhaust and then does work in the large cylinder instead of becoming lost into the outer air; this recovery of heat from the cylinders increases with the number of cylinders the steam passes through in succession.

Although however the compound system makes it possible to recover the internal condensation losses in the high-pressure cylinder, yet it has no effect on those which take place in the low-pressure cylinder. Sufficient superheat can, however, prevent the latter from occurring and this would tend to show the superiority of the single-expansion engine using superheated steam, over the compound engine using saturated steam, from the thermal point of view. But on the other hand, it must be remembered that the compound engine benefits by a high initial pressure and a prolonged expansion, and that these two points of superiority can in certain cases give it the advantage, from the point of view of economy, over simple engines using superheated steam, particularly if the locomotive has to keep up a large tractive effort; and this is incompatible with sufficient expansion in the case of the simple engine.

Compounding and superheating combined. — With sufficient superheat, condensation can be eliminated, while it remains in the case of compounds if saturated steam is used. Superheating combined with compounding can also give an advantage, although less than that obtained in the case of superheating applied to simple engines; moreover it gives the compound the advantage of the increase in volume of the superheated steam, and combined with the latter, it in its turn benefits by the prolonged expansion of the double-expansion engines.

The two systems thus do not mutually exclude each other; added together, they can in certain cases give the maximum efficiency.

Double expansion is however less convenient in the case of superheated steam than simple expansion. If the steam is superheated to a moderate extent, then, with a proper cut-off, the superheat will only prevent condensation in the high-pressure cylinder; if this effect is to extend to the low-pressure cylinder, the initial superheat has to be very high. But in this case the high-pressure cylinders escape cooling by the exhaust steam, a cooling which in the single-expansion locomotives contributes to keep the rubbing surfaces in order and facilitates the lubrication.

Moderate superheating at two successive stages, if it were realizable in practice, would, like high initial superheating, prevent all internal condensation in the high-pressure and the low-pressure cylinders; as compared with the former, it would have the advantage of reducing the mean temperature of the high-pressure valves and cylinders, of avoiding risks of any seizing, and of obtaining better tightness in the high-pressure valves and pistons, the steam being less superheated and consequently less fluid. But superheating in stages makes it necessary to have two superheaters, and that one for the lower pressure would naturally be very cumbersome owing to the large volume of the low-pressure steam, which has to be heated to a comparatively high temperature, by about 100° C. (180° Fahr.).

A practical difficulty of the same kind seems to exist if the lower-pressure steam, in which the principal condensation losses occur, is alone to be superheated.

BELGIUM.

In 1901, after a journey of enquiry in Germany, Messrs. Bertrand and Flamme, then manager and general inspector respectively, decided to try superheat on the Belgian State Railway. Three locomotives, two of which were in use and one of which was being built, were equipped with Schmidt superheaters, placed in large smoke tubes; it is not without interest to mention that it was in Belgium that, on the proposal of Mr. Flamme, the first application of the systems of superheaters placed in the smoke tubes, was made. Mr. Schmidt has acknowledged this in his periodical publications about superheated steam. Besides, the system of having a superheater in the smoke-box was not suited to the internal-cylinder locomotives of the Belgian State Railway.

The progress of the system of superheating was rapid; at the end of 1903, there were three locomotives with superheaters in use, twenty-three in 1905, fifty-six in 1906 and one hundred and twenty-four in 1907. At the end of March 1909, the stock included 236 superheated-steam locomotives in use and 208 were being built.

Superheater. — The Schmidt superheater placed in the smoke tubes is well known now.

It generally consists of three rows of six mild-steel solid-drawn tubes, having a

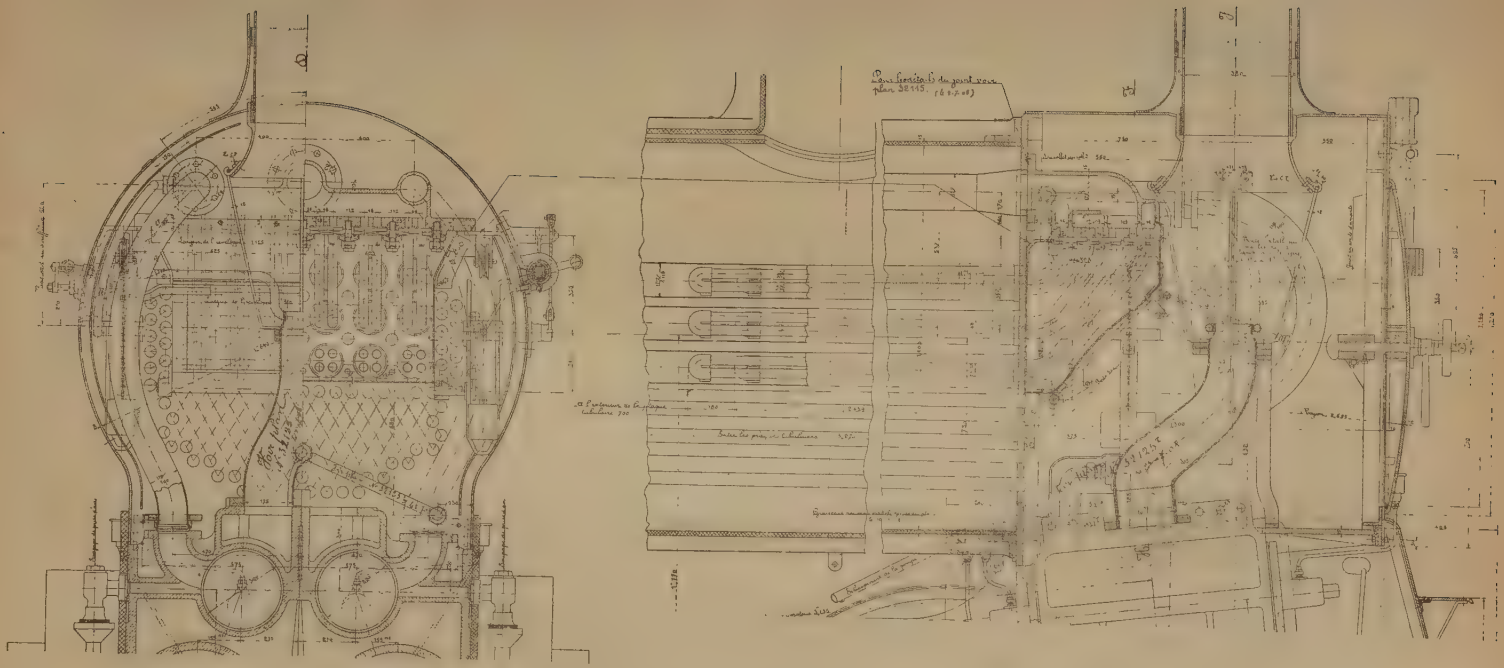

Fig. 1. — Belgian State Railway. — Locomotive type 32 using superheated steam.

Explanation of French terms : Raccord du souffleur = Connection with blast pipe. — Soupape de prise d'air = Air-admission valve. — A l'intérieur de la plaque tubulaire = Inside the tube-plate. — Entre les plaques tubulaires = Between tube-plates. — Graisseur nouveau modèle ajouté au plan = New lubricator added to design. — Échappement de la pompe = Overflow of pump. — Du collet du collecteur = From joint of collector. — Toile métallique, mailles de 8 m/m. Épaisseur du fil de fer 1 2/10 à 1 3/10 m/m = Wirework, mesh 5/16 inch. Thickness of wire 0·047 to 0·051 inch. — Rayon = Radius. — Joint en corde d'amiante = Asbestos-cord joint. — Vis = Screw.

diameter of 127 by 118 millimetres (5 × 4 5/8 inches), placed in the upper part of the nest of tubes (fig. 1). On the fire-box side, these tubes are contracted at two successive steps; originally they were screwed into the fire-box tube-plate; subsequently the ends of the tubes, turned smooth, were expanded and beaded over. The method of fixing now generally adopted is that shown in figure 2; the fire-box end of the tube is contracted, and has five grooves made in it, 2 millimetres (3/32 inch) wide by 0·5 millimetre (1/32 inch) deep; it is driven tight into the tube-plate, expanded and beaded over cold.

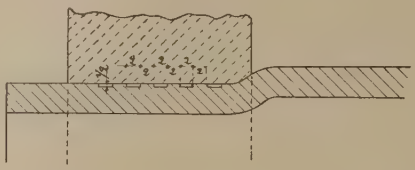

Fig. 2. — Belgian State Railway. — Locomotives using superheated steam. Method of fixing the superheater tubes in the tube-plate.

Each large smoke tube contains two superheater elements each consisting of two mild-steel solid-drawn tubes having a diameter of 34 by 27 millimetres (1 11/32 × 1 1/16 inches). The superheater tubes, at the fire-box side, are screwed into bend-connectors made of steel castings, crossing each other in pairs and having a thickness of 12 millimetres (15/32 inch) in the middle of the part exposed to the direct action of the flames. The distance between the end of the bend-connectors and the fire-box tube-plate varies between 0·66 and 0·75 metre (between 2 ft. 2 in. and 2 ft. 5 1/2 in.), according to type of locomotive. The tubes bend up in the smoke-box and their ends are secured to a steam collector by means of flanges fixed by four bolts. The joints of these flanges are made tight by asbestos soaked in linseed oil, and are afterwards painted over with a thin layer of oxide of iron mixed with linseed oil. The tubes of each element are kept apart by distance pieces forming part of the steel castings with which they are mounted. The centre of each element is placed above the middle of the smoke tube so as to make it easier to sweep the latter.

The U tubes through which the steam flows which is to be superheated, are connected at their ends with the two chambers of a collector, the one containing saturated steam, the other superheated steam. This collector is placed in the upper part of the smoke-box, against the tube-plate; it rests on two angle-irons riveted to the smoke-box, and care must be taken during the erection that it is well supported, and does not bear on the joint connecting it with the tube-plate. In order to ensure a certain mobility to the whole installation, a joint with a spherical-face ring is used (fig. 3).

In the smoke-box, the ends of the superheater tubes are enclosed in a sheet-iron

box. When running with regulator closed, no steam is passing through the small superheater tubes and the passage of the hot gases through the large smoke tubes is stopped by a damper kept closed by a counterweight. As soon as steam is turned on, the damper is opened automatically by a small steam piston in connexion with the main steam pipe. The length of stroke of this piston, and consequently the extent the damper is opened, can be controlled by the driver by means of a hand gear.

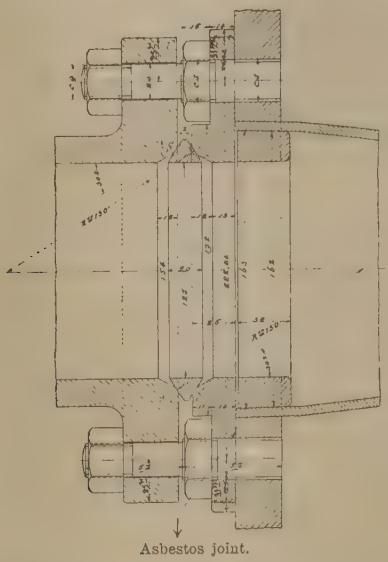

Fig. 3. — Belgian State Railway.
Joint connecting the collector of the superheater to the tube-plate.

Contrary to what is frequently the practice, this damper in the locomotives of the Belgian State Railway is in one piece and opens from above downwards (fig. 1). In its end position it is slightly below the horizontal so as not to interfere with the draught through the lower tubes, and at the same time to facilitate the descent of the cinders into the smoke-box. The current of gas passes through the large tubes in a direct line towards the chimney without having to be diverted and then sent on to the chimney, and it is perhaps to this arrangement designed by Mr. Flamme that it is to some extent due that no cinders accumulated in the large superheater tubes. It might have been feared that a damper made in one piece would become distorted and would no longer remain tight; but although in use for already a long time no signs of this are apparent.

Towards the end of 1908, the Belgian State Railway started ten locomotives

running which had been equipped with Schmidt superheater tubes, with quadruple passage of the steam. In this arrangement, each large tube contains one superheater element, consisting of three tubes connected at the ends by steel bends; the middle tube is bent to a U shape. The speed of the steam being accelerated in them (it passes through each element twice on a double journey), the inventor thinks that this must result in a more intimate commingling of the particles of steam which are still wet and of those which are already superheated, in a better cooling of the tubes and in their longer life. The ends of the tubes of each element are bent up in the smoke-box and expanded into a common horizontal flange fixed by a central vertical bolt to the collector (fig. 4).

The trials made with the two systems show that the amount of superheat resulting in a given time, is practically the same in both cases.

This design of superheater has been applied to forty locomotives which are being built.

Metals having a high coefficient of expansion must not be used for making superheaters. Tubes which by an error in the design had been made of copper instead of iron, rapidly became deformed in use.

Measuring the temperatures. — The pyrometers which have been in use for a long time are of the mercury-expansion type, and are supplied by the firms Schaeffer and Budenberg, by Steinle and Hartung, Socius mark, and by the *Société anonyme des robinetteries et chaudronneries* at Liége. They can be regulated and are non-compensated.

The pyrometer is placed in the exit tube of the collector, and the amount of superheat can be read off on a graduated sector placed in the driver's cab. At the side of the pyrometer, a pocket is provided in which a thermometer can be placed, as a check.

After making a series of experiments, the Fournier saturated-steam tension pyrometer has just been adopted. This instrument has great delicacy; its readings are not influenced, as in the others, by the variations of volume of the liquid enclosed in the pyrometer and its tubing, and they are independent of the air temperature.

Sweeping. — No system of sweeping the large smoke tubes has as yet been prescribed generally. Some workshops use wire brushes or tube scrapers. Others use compressed air, but the majority prefer a steam jet as being the most efficacious. In the two latter cases, the cleaning is effected from the smoke-box, while the locomotive is under steam.

As regards the interval between two consecutive cleanings, it varies from one depot to another; in some, this is done every day before starting; in others, every two days; others again, only once a week. The average interval is three days.

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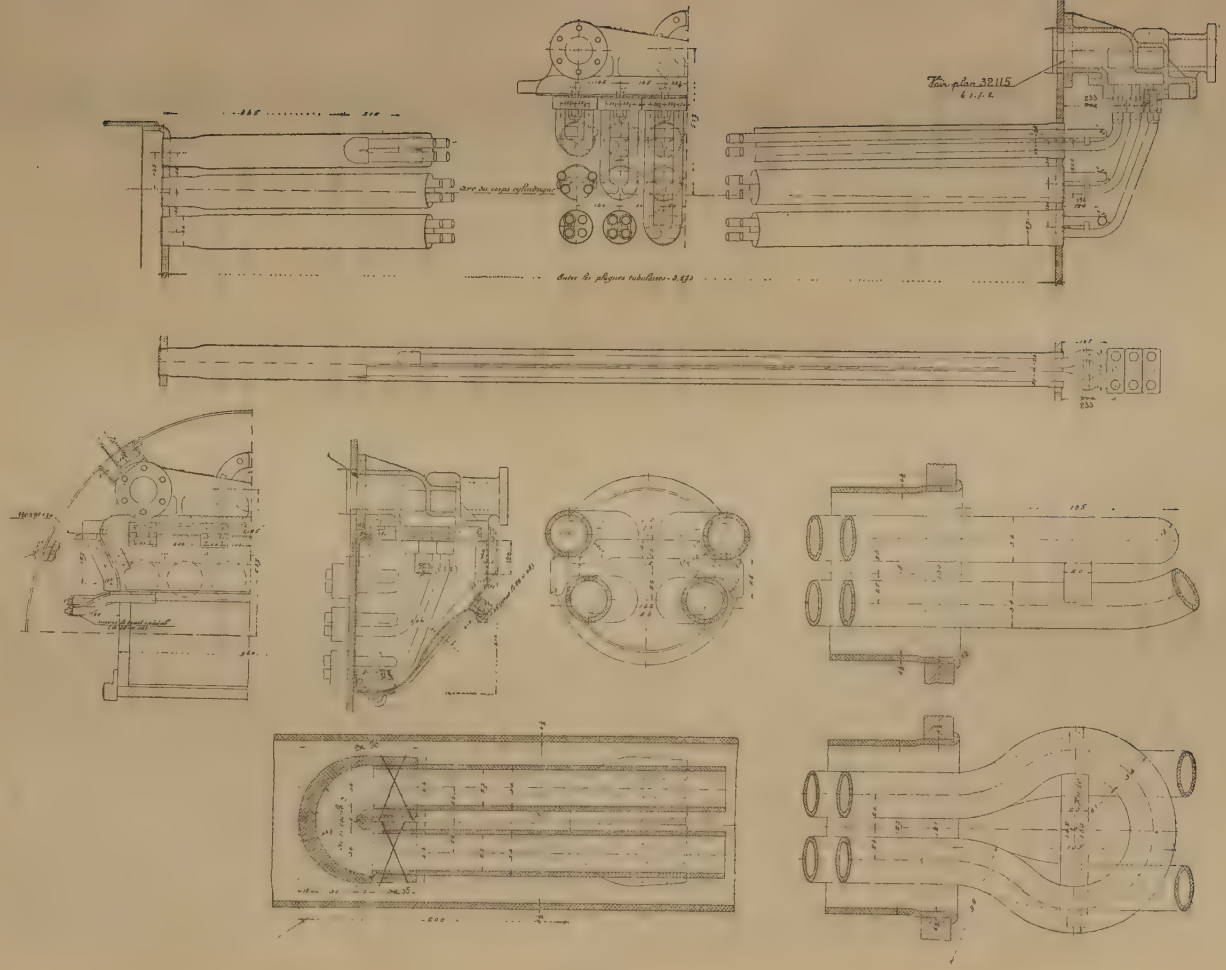

Fig. 4.

Explanation of French terms : Axe du corps cylindrique = Centre line of barrel. — Entre les plaques tubulaires = Between tube-plates. Suivre le trait spécial = Work to this special line. — Acier coulé = Steel casting. — Fonte = Cast iron.

The Schmidt superheater is a rationally-designed device. The steam coming from the boiler is sent through a series of tubes having a small diameter; it passes once or twice through each tube, making a double journey at a high speed (the clear cross-section of the tubes is on the average one twentieth of the piston area). The division of the steam into thin threads is particularly favourable to the effective superheating of all the particles, while at the same time the great speed ensures the cooling of the tubes and their preservation.

The superheater consists of a number of elements, simple, independent, easily accessible and replaceable, and free to expand.

The sweeping of the large tubes presents no difficulty. The driver has absolute control of the superheating; he adjusts it to suit the work the locomotive has to do.

As soon as the regulator is closed, the hot gases from the fire-box automatically cease to pass through the apparatus.

The superheated steam passes from the collector to the cylinders without drop of temperature.

Although located in the barrel, the superheater forms an apparatus independent of the boiler. Of solid construction, its object is to increase the temperature of the steam from 190 to 350° C. (from 374 to 662° Fahr.); the boiler proper, that is the most expensive and most complicated organ, is not subjected to any additional fatigue; it merely has to supply saturated steam at the same temperature as before the superheater was put in.

Valve gear for superheated steam. — As the Schmidt superheater placed in the smoke tubes makes it possible to obtain steam having a temperature of 300 and 350° C. (572 and 662° Fahr.), it follows that the essential details of the mechanism, the pistons, slides and stuffing boxes require modification, so that they may not seize when superheated steam is used.

Flat slide valves have been replaced, on account of the strong pressure acting on them, by piston valves; the steam is admitted between two conjugate pistons, while all that is acting on the outer faces of these is the pressure of the expanded steam; the packings generally provided in the case of superheated steam are consequently not necessary for the valve rods.

The driving pistons have a guided tail rod. Their weights rest in front on the guide of the tail and at the back on the slippers of the cross-head; they do not bear on the snap rings. These do not serve to support the piston; they only form a tight partition between the two surfaces; they are designed so as to press only gently against the cylinder so as to reduce its wear as well as that of the rings.

The pistons of the valves, like the driving pistons, have guided tail rods and rings giving little pressure.

The stuffing boxes of the pistons do not form a point of support for the latter; they are only to prevent leakage, while allowing the rod to move freely, as is particularly necessary in the case of superheated steam.

Driving pistons. — The driving pistons are steel castings. They are fixed on a coned part of their rods, and secured by a nut and pin. The rods, the tail rod and the cross-head are in one piece (fig. 5). The diameter of the piston is 3 millimetres ($^1/_8$ inch) less than that of the cylinder.

There are two or three piston rings. When in place, they project 1·5 millimetres ($^1/_{16}$ inch) outside the piston. They have on the outer face a circular groove 3 millimetres ($^1/_8$ inch) in diameter, and six holes 3 millimetres ($^1/_8$ inch) in diameter are drilled in at equal intervals. These openings connect the groove on the outer face of the ring with the groove in the piston. The pressure of the steam which finds its way into the latter is thus partly balanced; the groove also forms a sort of oil pocket for the lubrication of the cylinder. The intermediate ring has neither circular groove nor holes drilled in.

In order to produce tightness, the cuts in the rings are crosswise. They are kept in position by means of 5 millimetre ($^3/_{16}$ inch) steel pins; when in position, the ends of the ring are 7 millimetres ($^9/_{32}$ inch) apart. The edges of the piston and of the rings are slightly rounded.

On the Belgian State Railway, the tail rods of the driving pistons have no stuffing boxes. They are enclosed in a sheath connected with the cylinder. The sheath is provided inside with a grooved cast-iron guide.

Piston valves. — The valve pistons are built up of elastic segments, on the Schmidt principle. They consist of two cast-iron plates B and C (fig. 6), pressed together by a nut on the valve rod. Tightness is obtained by means of three cast-iron rings D, E, F. The ring F which is not cut is pressed tightly between the plates B and C. The tension rings D and E are secured to the plates B and C by set screws which prevent them from turning and which enter lugs cast on to the plates. Their surfaces of contact with the ring F are carefully ground. The cut ring E has on its outer side two grooves 3 millimetres ($^1/_8$ inch) wide and is pierced radially by twelve holes 3 millimetres ($^1/_8$ inch) in diameter regularly spaced in pairs. These holes connect the two outer grooves of the Ring E with a large groove in the centre ring F, which is not cut. This prevents the ring E from being pressed too strongly, by the action of the steam, against the lining and from producing too quick wear; similarly, during the period of compression, the pressure on the outer face of the ring is counterbalanced, a pressure which would tend to flatten and deform it and produce leakage. The lugs of plates B and C form supports for the rings D and E.

A jacket, with triangular openings for the introduction of the steam, completes the valve (fig. 7). When mounting, the large ports of the jacket are placed downwards, on the opposite side to that at which the steam arrives. The bars are arranged obliquely so as to distribute the wear on the rings equally over their whole circumference, and also in order to prevent the latter from turning. At the exhaust port, the openings into the jacket are rectangular, and placed upwards, to the side of the outlet.

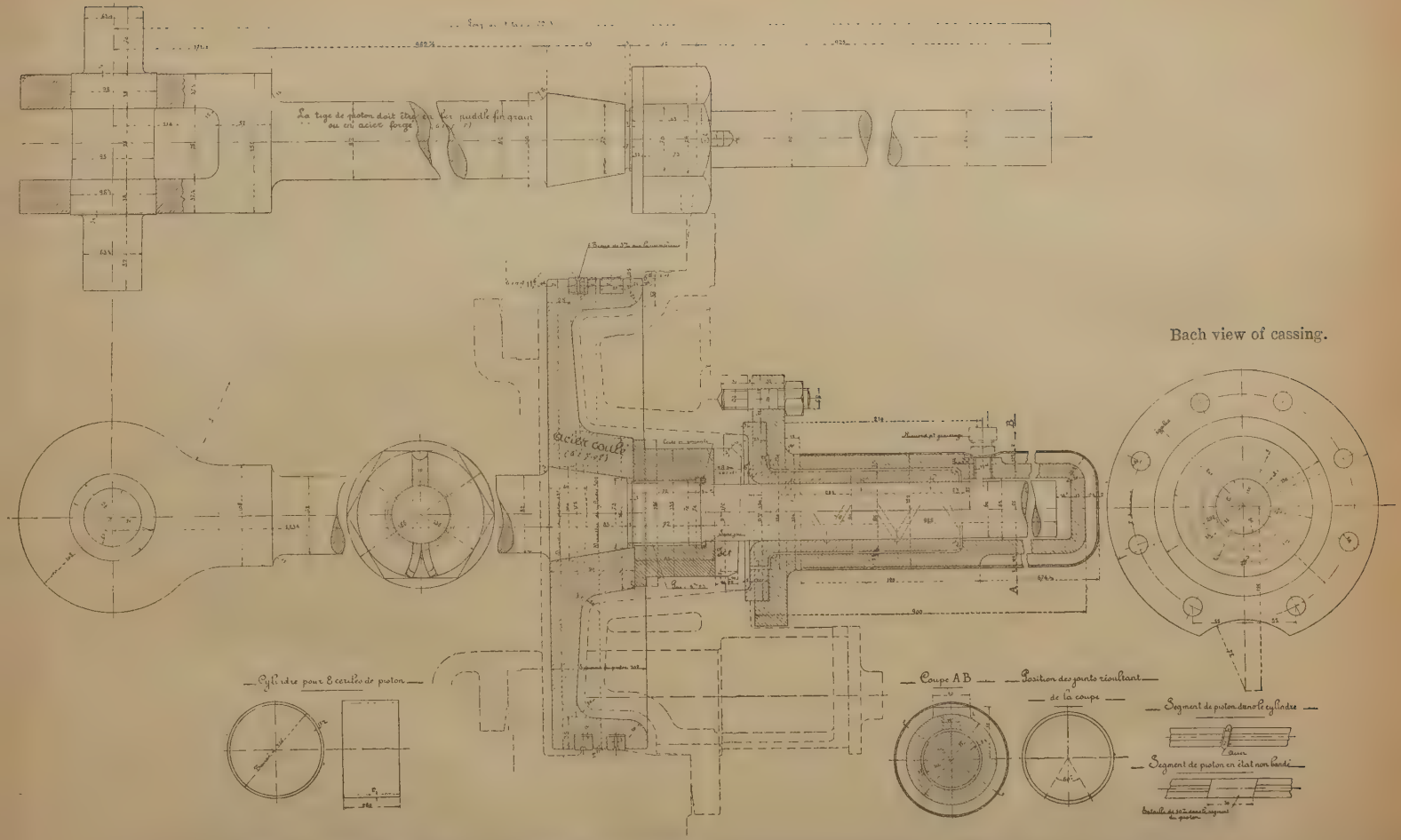
La tige de piston doit être en fer puddlé fin grain ou en acier forgé
Acier coulé
Bach view of casing.
Cylindre pour 8 cercles de piston
Coupe AB
Position des joints résultant de la coupe
Segment de piston dans le cylindre
Segment de piston en état non bandé

Fig. 5. — Belgian State Railway. — Locomotive type 32, equipped with Schmidt superheater. — Piston, piston rod and casing.

Explanation of French terms : La tige de piston doit être en fer puddlé fin grain ou en acier forgé = The piston rod must be of fine-grained wrought iron or of wrought steel. — Acier coulé = Steel castings. — Cylindre pour 8 cercles de piston = Cylinder for 8 piston ring. — Coupe AB = Section AB. — Position des joints résultant de la coupe = Position of joints resulting from cuts. — Segment de piston dans le cylindre = Piston ring in cylinder. — Segment de piston en état non bandé = Piston ring before putting in. — Entaille de 50 millimètres dans le segment

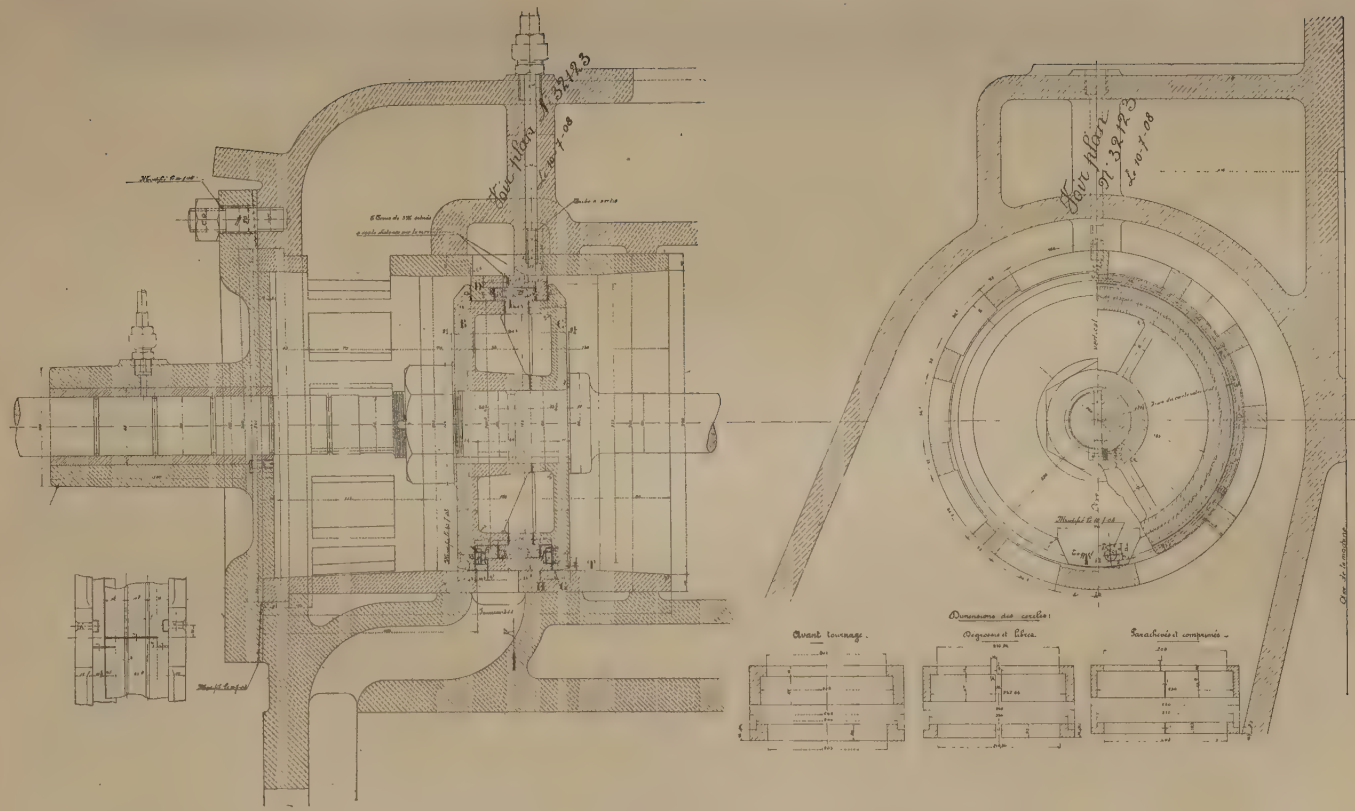

Fig. 6. — Belgian State. — Locomotive type 32, with superheater. — Piston valve.

*

Explanation of French terms : Dimensions des cercles = Dimensions of the rings. — Avant tournage = Before turning. — Dégrossis et libres = Turned down and free. Parachevés et comprimés = Finished and compressed.

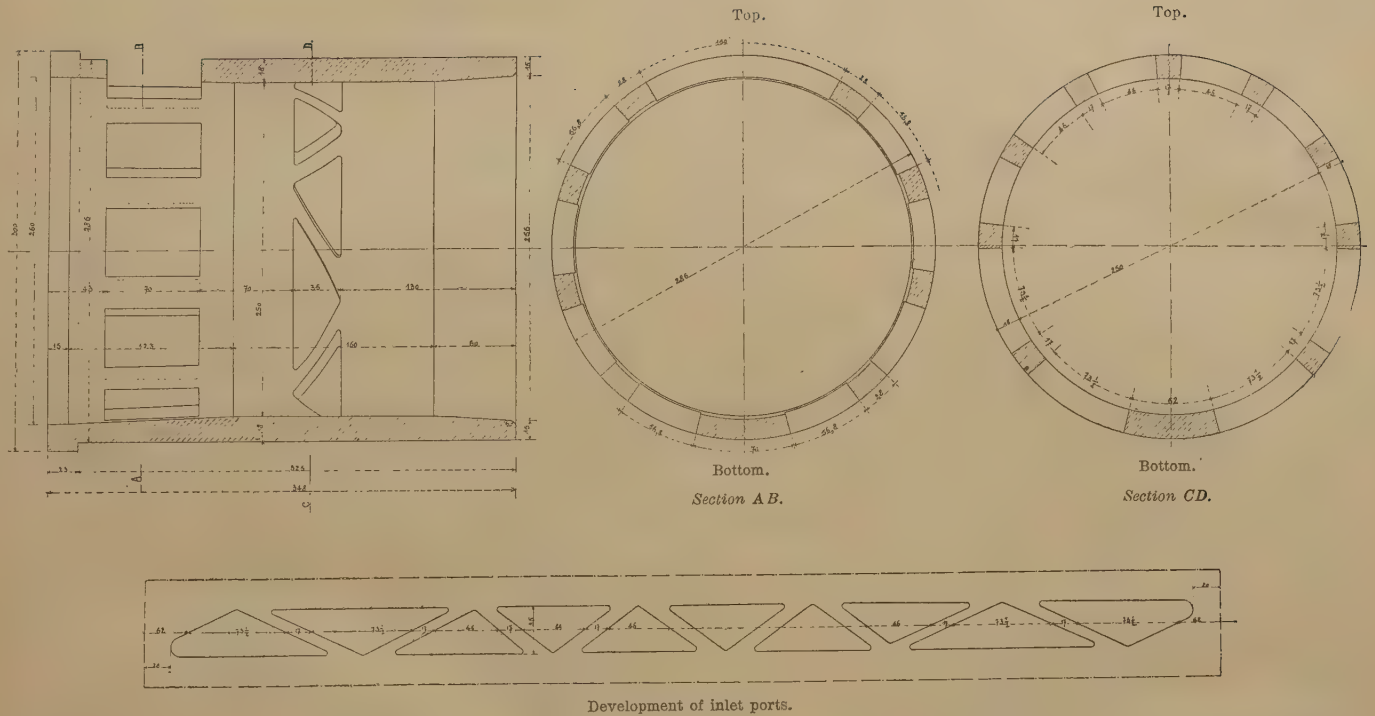

Fig. 7. — Belgian State Railway. — Details of liner.

The rods and tail rods of the piston valves being only in contact with the outflowing steam, it has not been necessary to supply them with any special packing. They only have circular grooves for lubrication and are guided in a long sheath of cast-iron cast in one piece with the bottom of the valve cylinder and fitted internally with a bronze lining (fig. 6).

One locomotive of the Belgian State Railway has been equipped, as an experiment, with a piston valve of the Schmidt system, 0·15 metre (5 $^{15}/_{16}$ inches) in diameter, with heated jacket, double admission and solid rings, not elastic. After running 60,632 kilometres (37,676 miles), it was found during a stationary trial that when the valves in their mean position were subjected to the action of steam at a pressure of 8 atmospheres (113·78 lb. per square inch), there was a loss of steam of 1,465 kilograms (3,230 lb.) per hour. It is however probable that there was too much play already at erection. Moreover, the loss of steam measured with the locomotive standing still does not enable us to determine how much is lost while running, when the lubrication is acting and covers the surfaces with a film which increases the tightness.

Apart from this single case of a valve with a solid ring, all the locomotives of the Belgian State Railway are fitted with the valves described above, with three rings, two of which are cut and are thin and elastic. With one large and single ring, whether cut or solid, the driver cannot continue his journey without risk of seizing in the cold part of the jacket; this is not the case with multiple and thin rings which contract as they enter the zone which is less expanded. On the Belgian State Railway, the instructions given to the staff driving the superheated-steam locomotives, do not contain any special instruction as regards any change in the stroke while running or at the moment the regulator is closed, and the considerable experience already obtained with locomotives using superheated steam has not shown that any trouble results.

Piston-rod packing. — The piston-rod packing is entirely metallic; it is designed so as to give to the movements of the rods while remaining tight. Figure 8 shows the design first adopted for the packing of the locomotives of the Belgian State Railway. The cast-iron ring F and the metal rings I are provided with oil grooves which at the same time serve to catch any steam due to leaks. The first annular cavity receives the steam which has found a way along the rod; the second takes part of the leakage from the first, the third takes part of the leakage from the second, and so on: the steam which has entered the annular cavities during admission returns to the cylinder during the expansion.

Near where the white-metal rings are placed, an annular space in connexion with the outer air is provided in the casing to cool it and keep it at a moderate temperature.

During admission, the rings are pressed against the rod by the action of the steam which acts on the ring F and by that of a spring having a force of 75 kilograms

(165 lb.). The spring and the steam pressure also drive the spherical ring C against its seat. The spherical ring G is kept in contact with its seat H by the pressure of the spring. The rings are of white metal, consisting of 80 per cent of lead and of 20 per cent of antimony; rings of special " frictionless " metal are now being tried with success, and they remain tighter. The rings are made in two semi-cylindrical parts arranged with a slight play between the ends and they are cut wedge-shaped so as to compress more easily when acted on by the steam. In order to give the packing play, it is necessary for the seats of the spherical rings to have a common centre.

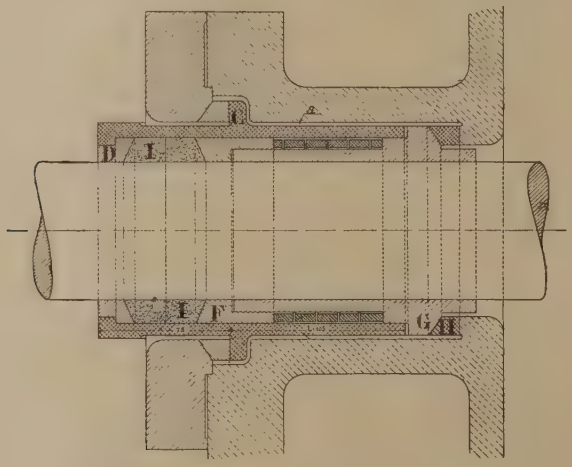

Fig. 8. — Belgian State Railway. — Piston rod packing, old type.

In the arrangement adopted in the locomotives supplied before 1908 (fig. 8), the spherical ring G is lifted from its seat during admission. The steam fills the annular space *a* between the packing and the cylinder. It may also happen that owing to imperfect adjustment ot the elements forming the gland, the elastic rings escape compression by steam while it is acting in the cylinder. The new arrangement (fig. 9) has been designed in order to obviate these two disadvantages. Moreover the casing, at the part where the white-metal rings are located, is in the air outside the stuffing box, and the annular space, which cools the rest of the packing, has been materially enlarged.

Cylinders. — A space is provided between the valve chest and the cylinder in order to avoid that the superheated steam should heat, as a pure loss, the outgoing steam and increase the work of compression.

The bottom of the cylinder is fitted with a safety valve whose diameter has been

increased to 0·10 metre (3 15/16 inches), to provide for possible water-hammer action at starting; this size of safety valve has been adopted in consequence of damage done to the bottom and to the covers; moreover on each valve chest, there is an atmospheric valve.

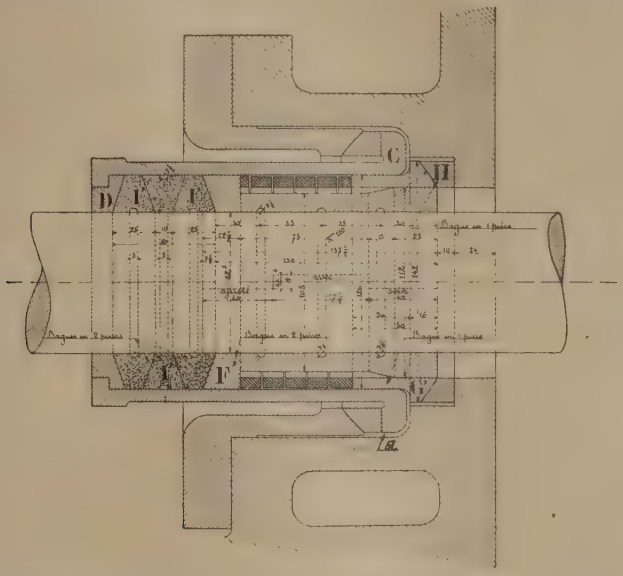

Fig. 9. — Belgian State Railway. — Piston road packing, new type.

In addition to these valves, thirty locomotives using superheated steam were also equipped (in 1908) with pipes connecting the two sides of the piston while running with regulator closed, so as to avoid drawing in gases from the smoke-box, excessive compressions and shocks to the gear. As soon as the regulator is closed, the driver opens the valve in the connecting pipe by means of a small air piston not acting automatically; he closes it before readmitting steam. As it is not indispensable that this valve should be opened each time the regulator is closed, as this is only really necessary when running down long gradients, and as moreover if it is frequently operated this may affect its tightness, it was decided not to make its action automatic.

Such connecting pipes are being fitted to 208 locomotives which are being built.

Lubrication. — All the rubbing surfaces which are in contact with the superheated steam are lubricated by means of mechanical lubricators or oil pumps. These devices are placed on the bearing of the locomotive and are operated by a rocking lever which is moved by the front crank or the cross-head of the slide-

valve rod. The oil is under pressure. The amount supplied can be regulated at will. They can be operated by hand, and in this way the whole piping can be filled, before starting or after standing still for some time. The patterns adopted are also fitted with stop valves at the points of insertion as well as with appliances for controlling the arrival of the oil at the points which are to be lubricated; they are fitted with a pipe for heating the oil in winter.

For each pair of single-expansion cylinders, there are eight oil pipes, two going to each valve chest, to the jackets, at the top, one to the middle of each cylinder, at the top, and one to each piston tail-rod casing.

The lubricators used on the Belgian State Railway, are of the Ritter, Friedmann, Zeyen and Bourdon types, as the builders may select. Other mechanical lubricators are now being tried.

At the back, the piston passes through a worsted box fixed to the cylinder and supplied with a needle lubricator. It has been found that the steam which escapes through the packing passes through the worsted to the lubricator, becomes condensed there and drives out the oil; and it has been found necessary to supply the pipe through which the oil passes with a fitting through which that steam can pass out.

The parts in contact with the superheated steam require to be lubricated with special oil, the oil known commercially as Wakefield oil being used; it costs 67 francs per 100 kilograms (£1·4*s.* 3*d.* per 100 lb.), and all experiments made with a view to replacing it by a cheaper oil have been failures.

Particular points to be observed in driving superheated-steam locomotives. — When leaving the sheds to join his train, the driver must open his drain-cocks; the steam is then as yet hardly superheated and the cylinders and valve gear are not yet heated. At the original start, or when starting again after a long stop, the same precaution is advisable, principally to get rid of the water which has condensed in the superheater tubes.

If the temperature of the steam exceeds 350° C. (662° Fahr.) the driver partly closes the damper by means of the hand gear; at temperatures above 350° C. (662° Fahr.) there is a risk of the complete decomposition of the oil.

When the regulator is closed, it is advisable not to open the fire-door until after the blower has been turned on; as the cross-section available for the passage of the hot gases has been reduced by closing the damper, there might otherwise be a risk of the flames coming out at the back.

As the locomotives using superheated steam have stronger cylinders, it is necessary, when less force is requird, to keep the cut-off as it is and to manipulate the regulator so as to maintain smooth running. If this is done, the final pressure of the steam is a little greater than with earlier cut-off and full pressure, but the greater superheat of the steam expanded at the regulator ensures the more complete elimination of the condensations during the cycle and makes up for the loss resulting

from shorter expansion. For instance, the temperature of saturated steam at a pressure of 14 kilograms per square centimetre (199·12 lb. per square inch) is 197° C. (387° Fahr.); if this temperature is increased to 350° (662° Fahr.), the superheat will be 350° — 197° = 153° C. (275° Fahr.). That steam can accordingly have its temperature reduced 153° C. (275° Fahr.) without any condensation resulting. If, the steam being produced at a pressure of 14 kilograms per square centimetre (199·12 lb. per square inch), it is only utilized in the cylinders at a pressure of 9 kilograms per square centimetre (128 lb. per square inch), the temperature remaining the same, the superheat will be 350° — 179° = 171° C. (308° Fahr.).

Care must be taken to avoid priming; any water carried over would quickly reduce the temperature of the superheated steam, even if we leave out of consideration that the superheater would have scale deposited in it more or less quickly; it is therefore advisable to run without excess of water and to throttle the steam when less work is done.

With the valve gear fitted to the locomotives of the Belgian State Railway, no special instructions have been found necessary as regards the adjustment of the travel of the valve when running, or as regards the closing of the regulator; the reasons for this were already given when describing the valve gear in use.

Diameter of the cylinders and heating surface of the superheaters. — The chief dimensions of the Belgian superheated-steam locomotives and of the similar saturated-steam locomotives, are given in the table below.

The examination of this table shows, in the first place, that superheated-steam locomotives work at the same pressures as saturated-steam locomotives. This pressure varies between the moderate limits of 12 to 14 atmospheres (between 170·67 and 199·12 lb. per square inch), according to type.

When superheated to 300° C. (572° Fahr.), the increase of volume, for an equal expenditure of coal, is 21 per cent, as has been shown previoulsy. This temperature of 300° C. (572° Fahr.) is attained in current practice when the locomotive is doing much or little work, whether in the way of load, or in that of speed. Now the increases in the capacity of the cylinders of the locomotives of types 15, 18 and 32 of the Belgian State Railway are only 14, 7·5 and 13 per cent respectively. When superheating was first used, high initial pressures on the pistons were feared, with their possible consequences, particularly as regards the heating of the rods and the bearings and the proper action of the springs. Experiments are being carried out from these different points of view on a locomotive of type 32; the diameter of its cylinders has been increased to 511 millimetres (1 ft. 8 $^{1}/_{8}$ in.). But already in the case of type 32 with cylinders 500 millimetres (1 ft. 7 $^{11}/_{16}$ in.) in diameter, it has become necessary to fit the steel boxes with bronze and to increase the length of the bearing on the barrel so as to reduce the pressure per unit area, which has been effected by widening the side faces of the bearing down to 25 millimetres (1 inch) below the centre line of the axles.

—	Locomotive type 32.		Locomotive type 35.		Locomotive type 18.		Locomotive type 15.		Locomotive type 18bis with superheater.	Locomotive type 9, four equal cylinders, with superheater.
	Without superheater.	With superheater.	Without superheater.	With superheater.	Without superheater.	With superheater.	Without superheater.	With superheater.		
Type of locomotive.	0-6-0	0-6-0	4-6-0	4-6-0	4-4-0	4-4-0	4-4-2	4-4-2	4-4-0	4-6-0
Diameter of driving wheels, in metres . .	1·520	1·520	1·600 1·700	1·600 1·700	1·980	1·980	1·800	1·800	1·980	1·980
Diameter of cylinders, in metres	0·470	0·500	0·500 0·520	0·520	0·482	0·500	0·440	0·470	0·500	0·445
Length of stroke of piston, in metres . . .	0·660	0·660	0·660	0·660	0·660	0·660	0·610	0·610	0·660	0·660
Working pressure, in atmospheres . . .	13	13	14	14	13	13	12	12	13	14
Grate area, in square metres.	2·5235	2·5235	2·84	2·84	2·07	2·07	2·50	2·50	2·07	3·18
Direct heating surface, in square metres. .	11·0169	11·0300	14·91	14·99	12·1716	12·2100	11·70	11·72	12·21	16·44
Indirect heating surface, internal, in square metres	104·4039	85·1000	158·25	130·05	115·4540	89·9000	85·52	69·15	97·60	138·87
Superheating surface, external, in square metres	...	21·5100	...	33·10	...	24·5100	...	16·98	26·79	37·80
Ratio of superheating surface to total heating surface	...	0·223	...	0·228	...	0·239	...	0·210	0·244	0.243
Weight empty, in kilograms.	46,000	47,700	63,350	65,150	49,200	51,000	53,125	...	54,000	...
Weight in working order, in kilograms . .	49,800	51,600	69,580	71,500	53,350	55,150	64,000	...	58,900	...

The examination of this table also shows that a superheated-steam locomotive is about 1,900 kilograms (4,200 lb.) heavier than a saturated-steam locomotive of the same type, with flat slide valve. The price paid by the Belgian State Railway for equipping such a locomotive with a superheater and with piston valves including the mechanical lubrication and the pyrometer, varies between 4,000 and 5,000 francs (between £160 and £200), according to the state of the market and the type of the locomotive. To this the royalty has to be added. The total extra expense is only a slight addition to the price.

Lighting up, in the case of superheated-steam locomotives, is done with the damper closed; the indirect heating surface of the locomotives using superheated steam, already less than than that of similar locomotives using saturated steam, is reduced still further by the internal surface of the large tubes. The superheated-steam locomotives accordingly take about 15 per cent longer than the ordinary locomotives before they are in full steam; the same applies to the coal consumption which is increased by 8 to 10 per cent each time the fires are started.

Result of trials of superheoted-steam locomotives. — Trials of superheaters were begun in 1904. Towards the end of the preceding year, the Belgian State Railway

had started working three locomotives equipped with the Schmidt superheater; one new locomotive of type 35, with wheels 1·60 metres (5 ft. 3 in.) in diameter, and two old passenger locomotives, 115 and 828, which had to have their tube-plates and cylinders renewed. The locomotive 115 was equipped with Schmidt valves with solid rings, while the two other locomotives, like all the locomotives delivered since, had valves with elastic rings.

The chief dimensions of the two locomotives 115 and and 828 are given below.

—	Locomotive type 2		Locomotive 115	
	Without superheater.	With superheater.	Without superheater.	With superheater.
Type of locomotive.	0-6-0	0-6-0	2-4-0	2-4 0
Diameter of driving wheels, in metres	1 70	1·70	2·09	2·09
Diameter of cylinders, in metres	0·450	0·450	0·440	0·480
Length of stroke of piston, in metres	0·600	0·600	0·600	0·600
Working pressure, in atmospheres	9	9	8	8
Grate area, in square metres	2·7667	2·7667	1·7544	1·7544
Direct heating surface, in square metres	10·9200	10·94	7·091	7·091
Indirect heating surface, internal, in square metres	109·3830	93·33	100	80·71
Superheating surface, external, in square metres	...	17·70	. .	16·50
Ratio of superheating surface to total heating surface	...	0·169	...	0·187
Weight empty, in kilograms	...	38,100	...	38,500
Weight in working order, in kilograms.	...	41,200	...	41,350

Locomotive 115, an engine of not much power, was utilized from the beginning for hauling suburban trains on a level line. But little differences were observed between the consumption of this locomotive and that of a similar locomotive not equipped with a superheater and used alternately for the same service. Each time the regulator was closed, that is to say during the periods of slacking and stopping, the superheat temperature shown by the pyrometer fell 30 or 40° C. (54 or 72° Fahr.); moreover, after starting, a certain time was necessary until the temperature again rose to 260° C. (500° Fahr.); and that temperature had hardly been attained before it was again necessary to close the regulator in order to stop at the next station. The superheater could hardly work under normal conditions for any length of time except between two stations 10 kilometres (6·2 miles) apart.

Locomotive 115 was subsequently used for hauling through trains having a weight

which practically corresponded to the limit of power of the locomotive without superheater; this locomotive, with a normal superheat of 80° C. (144° Fahr.), then showed an economy of fuel of about 14 per cent at the end of a trial period ten days long in the case of each locomotive.

Similar results were obtained with locomotive 828, which is also an engine of not much power. While the coal economy was nearly nil with small suburban trains with frequent stops, it amounted up to 14·8 per cent with through trains forming maximum loads.

The economies of 14 and 14·8 per cent given above apply solely to the coal burnt while the locomotive is hauling the train.

The trials made with the locomotives of type 35 with wheels 1·60 metres (5 ft. 3 in.) in diameter were with two new locomotives, one equipped with the Schmidt superheater, and one without. These two locomotives were alternately used for hauling the fast goods trains between Schaerbeek and Arlon (199 kilometres [123·7 miles], and the semi-direct passenger trains between Schaerbeek and Namur (62 kilometres [38·5 miles]). The profile of the Schaerbeek-Namur-Arlon line is very undulating, and there are many long gradients of 16 per mil. Each locomotive hauled twenty-four goods trains (average weight, 250 tons) and twelve passenger trains (average weight, 150 tons). The distance run by each locomotive was 11,500 kilometres (7,146 miles). The economy of coal calculated from the total consumption of the two locomotives was 13·33 per cent in favour of that with superheater.

Trials were afterwards made with the same locomotives, on through passenger trains on the line from Brussels to Charleroi (56 kilometres [34·8 miles]), which includes a series of gradients of 13 per mil. These trains have three intermediate stops, at about equal distances apart. During ten days during which the climatic conditions remained unchanged, the two locomotives alternately hauled one and the same train weighing 250 tons. The saving in favour of the superheated-steam locomotive effected during these runs amounted to 14·3 per cent of fuel and 18·6 per cent of water. Moreover at the top of the 13 per mil gradients the speed of the superheated-steam locomotives was about 10 per cent higher.

Investigations into the efficiency of the superheaters. — Although locomotives 115 and 828 when hauling suburban trains with frequent stops at short intervale did not show any appreciable superiority over similar locomotives using saturated steam, superheating has however been found efficient with trains of this kind if they are heavy. Between Antwerp and Brussels, a flat line 44 kilometres (27·3 miles) long, a passenger train weighing 400 tons was hauled by a locomotive of type 35 and there were twelve intermediate stops, each for about 1 minute; the pyrometer varied between 260° C. (500° Fahr.) at the start and 305° C. (581° Fahr.) when the regulator was closed; the temperature rose quickly during the start. The same locomotive, with a cut-off at 30 per cent, hauled a trough train weighing

350 tons; there was no stop, and the temperature indicated by the regulator varied between 300 and 330° C. (between 572 and 626° Fahr.). At the moment of starting the pyrometer marked 200° C. (392° Fahr.); at kilometre 7 (mile 4·35) it marked 310° C. (590° Fahr.).

When stops are frequent and long, as happens with certain kinds of good trains, superheating is less economical. The following observations were made on a goods train running from Antwerp to Schaerbeek (41 kilometres [25·5 miles]), which had ten intermediate stops of at least ten minutes; this train was hauled by a locomotive of type 32 working with the cut-off at 30 per cent. The highest temperature of the superheated steam was 270° C. (518° Fahr.); during the stops the superheater became colder and the pyrometer fell to 200° C. (392° Fahr.). The temperature rose only slowly when the regulator had been opened. On the short sections, of 2 to 3 kilometres (1·25 to 1·86 miles), the maximum was only 250° C. (482° Fahr.), while when the same locomotive was hauling a through train weighing 860 tons, cut-off at 40 per cent, the temperature of the superheater varied between 275 and 290° C. (between 527 an 554° Fahr.), reading 275° C. (527° Fahr.) being obtained after fifteen minutes run.

Superheating is thus above all to be recommended for long runs without stops, and it is the more advantageous, the heavier the work the locomotive has to do; it is still to be recommended, but to a less extent, in the case of heavy suburban trains with frequent but short intervals. Its efficiency is much reduced in the case of light suburban trains or of goods trains with stops of some duration at frequent intervals.

The superiority of superheated-steam locomotives does not depend only on the kind of train hauled; it is also connected with the profile of the lines. Lines on the flat on which the work the locomotives have to do remains practically constant and uninterrupted are very suitable for superheated-steam locomotives. The variations in the temperature of the superheated steam are then insignificant. The instances of the through passenger and goods trains between Brussels and Antwerp, mentioned above, prove it; this is also corroborated by other kinds of trials made between Brussels and Ostend (line on the flat, 125 kilometres [77·7 miles] long), with an express train weighing 275 tons (270 English tons) and hauled by a locomotive of type 18*bis*. The temperature of the superheated steam was 290° C. at kilometre 6 (554° Fahr. at mile 3·73), and 300° C. at kilometre 19 (572° Fahr. at mile 11·80); it afterwards varied between 300 and 305° C. (between 572 and 581° Fahr.) during the whole time that the regulator was open. Several times when this was closed, for slacking, the pyrometer dropped 25 to 30° C. (45 to 54° Fahr.), but it quickly rose to about 300° C. (572° Fahr.) as soon as steam was turned on again.

Lines with long and steep gradients are also suitable for superheated-steam locomotives as the temperature curves recorded during the express runs Brussels-Liége, Brussels-Quévy and Brussels-Charleroi (figs. 10 to 12) show; the steam very quickly

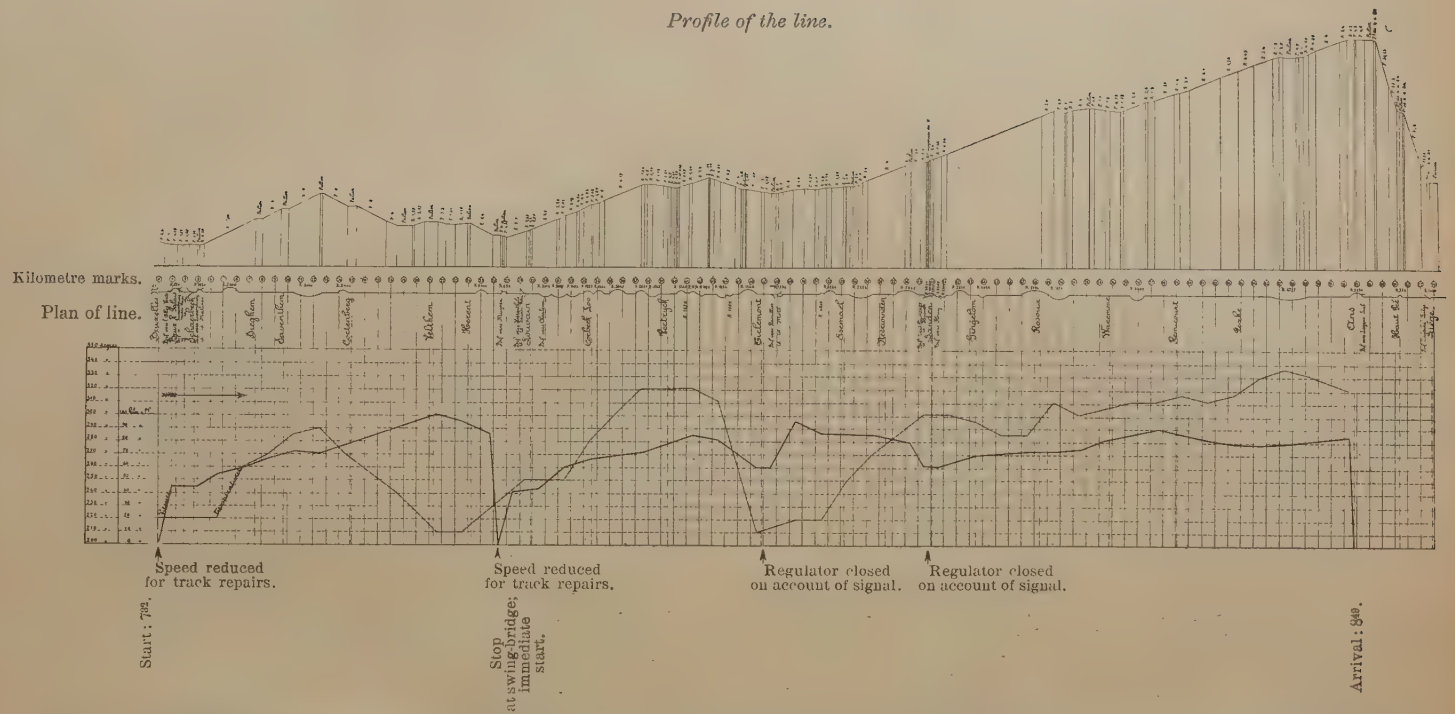
Profile of the line.
Kilometre marks.
Plan of line.
Speed reduced for track repairs.
Speed reduced for track repairs.
Regulator closed on account of signal.
Regulator closed on account of signal.
Start : 7h9.
Stop at swing bridge; immediate start.
Arrival : 9h0.

Fig. 10. — Belgian State Railway. — Locomotives 3303 with four equal cylinders and superheater. — Diagram showing running of train 610 on 31 Mai 1905, between Brussels and Ans, and superheat temperatures. — Weight hauled : 327·5 tons (322·3 English tons). — Composition : 2 vans with 6 wheels, 11 carriages with 6 wheels and one saloon carriage on bogies.

Explanation of French terms : 100 kilomètres à l'heure = 100 kilometres (62 miles) per hour. — Vitesse = Speed. — Température = Temperature.

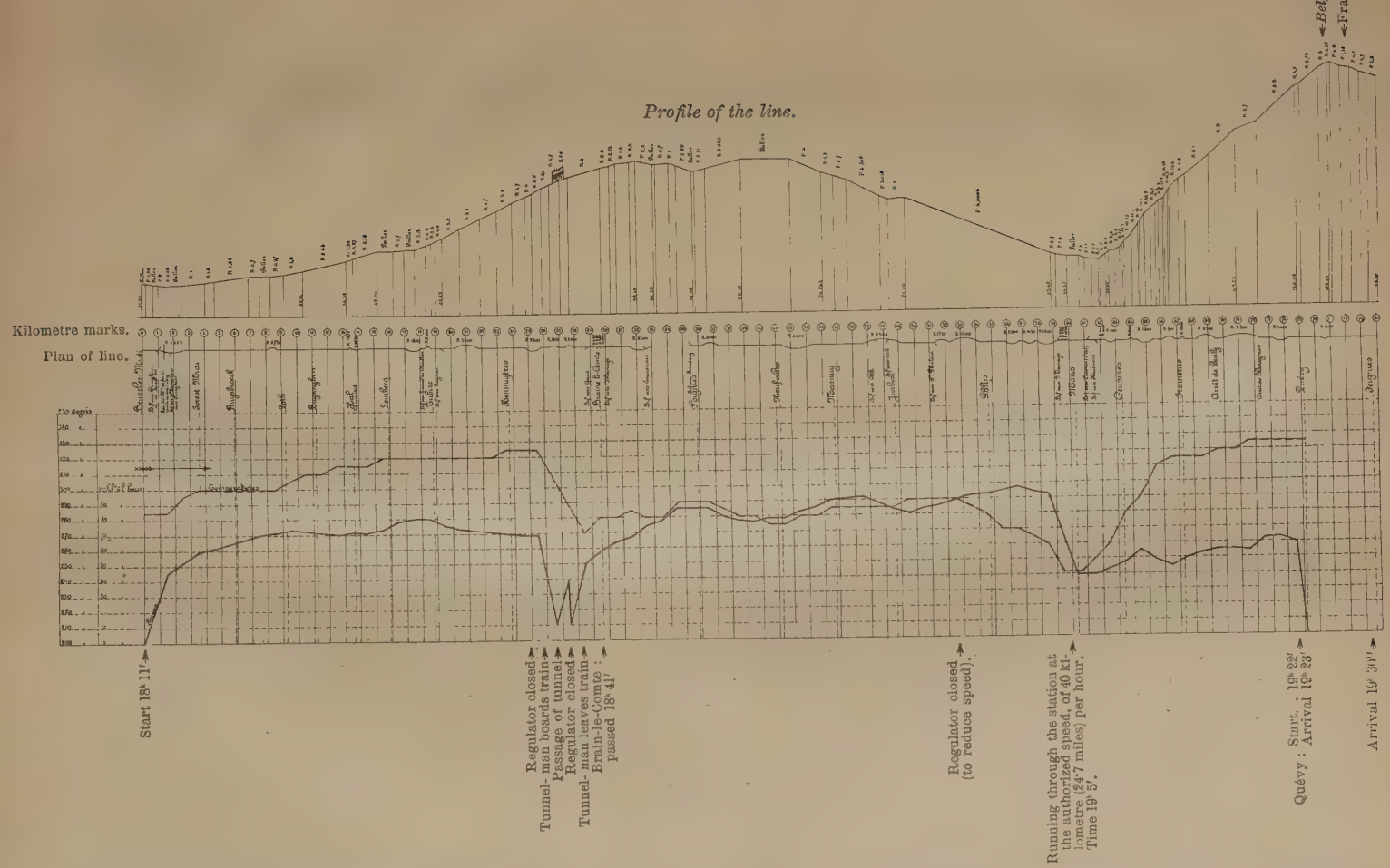
Profile of the line.
Kilometre marks.
Plan of line.
Start 18h 11'
Regulator closed
Tunnel-man boards train
Passage of tunnel
Regulator closed
Tunnel-man leaves train
Brain-le-Comte : passed 18h 41'
Regulator closed (to reduce speed).
Running through the station at the authorized speed, of 40 kilometre (24·7 miles) per hour. Time 19h 5'.
Quévy : Start. 19h 22'
Arrival 19h 23'
Arrival 19h 30'

Fig. 11. — Belgian State Railway. — Locomotive 3234 type 35, with wheels 1·7 metres (5 ft. 7 in.) in diameter and superheater. — Diagram showing runnig of train 128 in 6 July 1905, between Brussels and Feignies, and superheat temperatures. — Weight hauled : 355 tons (349·4 English tons. — Composition : 1 van and 8 carriages with bogies and 2 cerriages with 6 wheels.

N. B. — The speeds and temperatures between Quévy and Feignies were not recorded.

Explanation of French terms : Températures = Temperature. — Vitesse = Speed. — 50 kilomètres à l'heure = 50 kilometres (31 miles) per hour.

Profile of the line.
Kilometre marks.
Plan of line.
Maximum speed authorized on this line : 85 kilometres (52·8 miles) per hour.
Start 8h28'.
Speed reduced for track repairs.
Speed reduced at signal.
Regulator closed
Speed reduced at distant signal
Running through the station at the authorized speed of 40 kilometres (24·9 miles) per hour.
Nivelles-Est : stop 1 minute
Regulator closed
Speed reduced at distant signal
Luttre : stop 1 minute
Regulator closed
Gosselies Courcelles : stop 1 minute
Roux : stop 1 minute
Marchienne-au-Pont : stop 1 minute
Arrival : 9h16'

Explanation of French terms : Températures = Temperature.
Vitesse = Speed. — 100 kilom. à l'heure = 100 kilometres (62 miles) per hour.

Fig. 12. — Belgian State Railway. — Locomotive 3207 type 35 with wheels 1·6 metres (5 ft. 3 in.) in diameter and superheater. — Diagram showing running of train 1646 on 27 June 1905, between Brussels and Charleroi, and superheat temperatures. — Weight hauled : 382·5 tons (376·5 English tons). — Composition : 1 van with 6 wheels, 12 carriages with 6 wheels, 2 carriages with 4 wheels, and 3 saloon carriages on bogies.

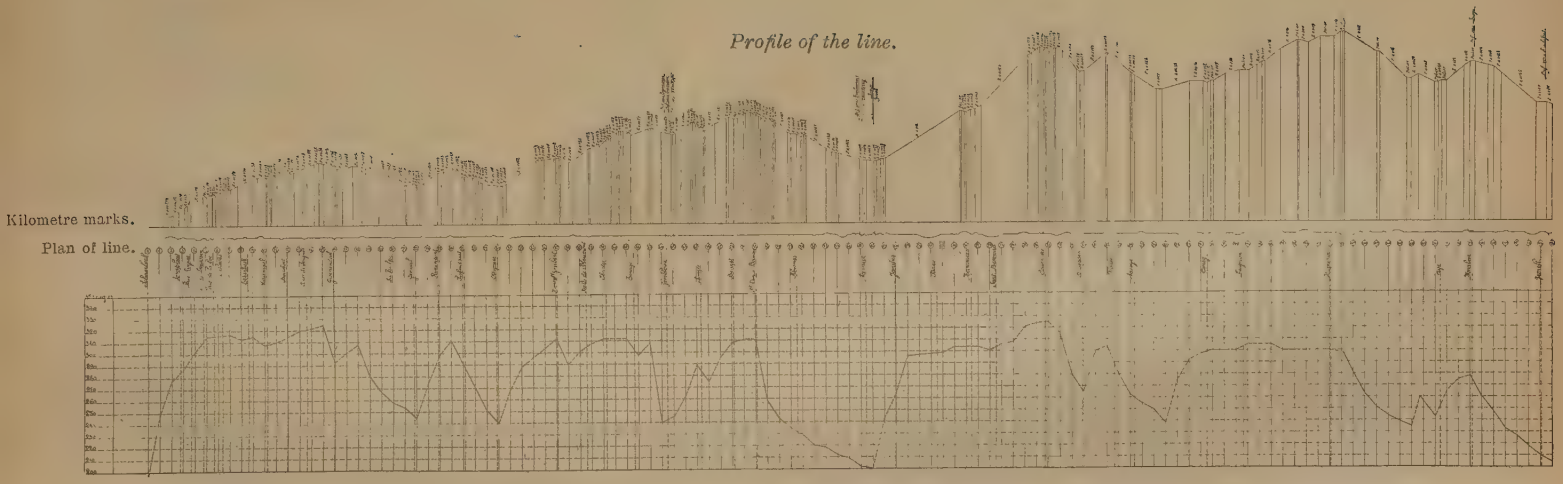

Fig. 13. — Belgian State Railway. — Diagram of temperatures recorded by the Fournier instrument on locomotive type 32 with superheater hauling an accelerated goods train fully loaded between Schaerbeek and Jemelle.

attains a high degree of superheat on such undulating profiles. The resulting saving in water makes it possible to feed the boiler at longer intervals on up gradients and so avoid the objectionable drop of pressure which generally results.

Superheating is equally to be recommended on saw-teeth gradients of a certain length. The locomotives work well there. At the top of the rise, the superheater has been raised to such a temperature that it only cools partially when the regulator is opened. The diagram shown in figure 13 illustrates this; it shows the temperature curve obtained with a Fournier pyrometer on a fast heavy through goods train running on the line from Schaerbeek to Jemelle. If we exclude the down gradients which precede the stops of 18 minutes at Ottignies and Gembloux, as well as the descents to Namur and Jemelle, there is generally a difference of not more than 50° C. (90° Fahr.) at most, between the temperature of the steam when the regulator is closed and its subsequent reopening, and moreover the temperature of the superheated steam rises again rapidly.

It also follows from the trials made and from the analysis of the temperature curves that the additional power obtained by superheating is not available at the start. It is obtained only after running a certain variable distance, depending on the nature of the train and the profile of the line.

Results of comparative trials with one locomotive of type 35 without superheater, one locomotive of type 35 with superheater, and one compound locomotive of type 8 without superheater. — The following are the chief particulars of these three locomotives :

—	Type 35 without superheater.	Type 35, with superheater.	Type 8, compound, without superheater.
Number of wheels	4-6-0	4-6-0	4-6-0
Diameter of driving wheels, in metres	1·70	1·70	1·80
Diameter of cylinders, in metres	0·52	0·52	0·36 high pressure. 0·60 low pressure.
Length of stroke of piston, in metres	0·66	0·66	0·64
Working pressure, in atmospheres	14	14	15·5
Grate area, in square metres	2·84	2·84	3 08
Direct heating surface, in square metres.	14·91	14·99	16·23
Heating surface inside the tubes, in square metres	158·25	130·05	144 50
Superheating surface, external, in square metres.	...	33·10	...
Weight empty, in kilograms	63,350	65,150	69,450
Weight in working order, in kilograms	69,580	71,500	75,500
Adhesive weight, in kilograms	50,700	51,500	54,000
Weight of tender, in working order, in kilograms.	47,900	47,900	47,900

The trials were made on the runs Brussels-Feignies (79 kilometres [49 miles] and Quévy-Brussels (75 kilometres [46·6 miles]), with the booked trains 122 and 115 These trains are both express passenger trains between Brussels and Paris and *vice versa*. Train 122 has one stop at Quévy and train 115 runs through from Quévy to Brussels.

The Brussels-Feignies line rises nearly continuously from Brussels to Braine-le-Comte (30 kilometres [18·6 miles]), with gradients from 2·5 to 5 per mil; the 17 kilometres (10·5 miles) between Mons and the frontier also rise continuously, with gradients varying from 8 to 18 per mil. Seventeen mintes are allowed for this section. In the opposite direction the line rises continuously, with a gradient of 4·7 per mil, over about 20 kilometres (12·4 miles) after leaving Mons. The dynamometer car of the Belgian State Railway was placed immediately behind the tender.

The fuel used consisted exclusively of briquettes of varying origin containing 5 per cent of ash as a maximum.

The results of the trials are given in the annexed tables I to III.

The examination of tables I to III shows that :

1° The locomotive of type 35 using superheated steam has shown as compared with the similar locomotive without superheater an average economy of 29·64 per cent of coal and of 28·67 per cent of water, per horse-power measured at the draw-bar, while developing on ascending gradients from 11·8 to 19·5 per cent more power;

2° As compared with the compound type 8, type 35 using superheated steam has used 5·47 per cent of coal and 14·67 per cent of water less, per horse-power measured at the drawbar.

Results of comparative trials with a two-cylinder locomotive of type 18 using superheated steam, and an Atlantic four-cylinder compound without superheater. — The following of these two locomotives :

—	Type 18 with superheater.	*Atlantic* compound, without superheater.
Number of wheels	4-4-0	4-4-2
Diameter of driving wheels, in metres	1·98	1 98
Diameter of cylinders, in metres	0·500	0·36 high pressure. 0·60 low pressure.
Length of stroke of piston, in metres.	0·66	0·64
Working pressure, in atmospheres	13	15·5
Grate area, in square metres	2·07	3 03
Direct heating surface, in square metres.	12·21	16·17
Heating surface inside the tubes, in square metres	89·90	218·81 (Serve tubes)
Superheating surface, external, in square metres	24·51	...
Weight empty, in kilograms	51,000	68,103
Weight in working order, in kilograms	55,150	74,500
Adhesive weight, in kilograms	35,960	36,900
Weight of tender in working order, in kilograms	47,900	47,900

*

Table I. Train n° 122 Bruxelles-

TYPE OF LOCOMOTIVE.	Date of trial.	State of weather.	Load haul at tender drawhook in tons.
1. — Type 35 without superheater	18 April 1906.	Rain and wind.	361·6
	20 — —	Fine weather.	327·3
	23 — —	Dry weather. Side wind.	338
	27 — —	Fine weather.	328·5
	30 — —	— —	294·8
	4 May —	— —	289·1
	29 — —	Dry weather. Wind.	297
Average.	...	...	...
2. — Type 35 with superheater	19 April 1906.	Wind. Rails damp.	329·3
	21 — —	Fine weather.	300·9
	24 — —	Rain and wind.	306·2
	28 — —	— —	340
	1 May —	Fine weather.	321·3
	5 — —	— —	331·3
	26 — —	Rain and wind.	306·3
Average.	...	...	...
3. — Type 8 with fixed exhaust and Serve tubes	9 May 1906.	Fine weather.	323
	11 June —	— —	294·8
	16 — —	Dry weather. Wind.	334
Average.	...	...	...
4. — Tupe 8 with fixed exhaust and smooth tubes	11 May 1906.	Fine weather.	320·5
	28 — —	Id.	329·1
Average.	...	...	...
5. — Type 8 with variable exhaust and Serve tubes	12 June 1906.	Fine weather.	297·2
	15 — —	Damp weather.	318·9
	18 — —	Fine weather.	328·4
Average.	...	...	...
Average, type 8.	...	...	...

es (79 kilometres). Table I.

Consumption			Section where the locomotive developed most power.				Actual times of running, from passing Mons till arrival at Quévy. — Time specified : 17 minutes.	Stop at Quévy, time in seconds occupied over 2,150 metres with gradient of 8 per mil.
urney.	per horsepower-hour (270,000 kilogrammetres at the tender drawhook).		between kilometre-marks 21-25 (+ 5 millimetres).		between kilometre-marks 245-236 (+ 8, + 9, + 14 millimetres).			
Briquettes, in kilograms.	Water, in kilograms.	Briquettes, in kilograms.	Mean speed recorded, in kilometres per hour.	Mean power developed at drawhook of tender, in horse-power.	Mean speed recorded, in kilometres per hour.	Mean power developed at drawhook of tender, in horse-power.		
1,385	20·4	2,420	61·5	553	44·2	625	20′	257″
1,488	20·9	2,530	65·5	642	47·8	665	18′13″	228″
1,420	20·7	2,350	66·8	661	50·3	684	17′38″	237″
1,530	21·2	2,560	68·7	605	48·6	695	17′54″	232″
1,345	22·3	2,440	70·4	630	50·5	641	17′28″	211″
1,465	22·2	2,630	66·5	613	54·5	695	16′50″	241″
1,344	22·5	2,400	66	608	53·2	703	16′44′	216″
...	21·48	2,502	...	616	...	672	...	...
1,049	16	1,730	67·3	651	53·1	750	17′ 1″	188″
1,025	15·7	1,680	73·2	670	57·8	745	15′59″	208″
1,013	15·8	1,670	72·8	692	56·2	745	16′18″	189″
1,216	14·2	1,780	66·2	775	48·5	—	18′20″	213″
1,156	—	—	73	—	50·3	—	16′54″	216″
1,145	—	—	71·8	—	55·8	—	15′40″	203″
937	15	1,590	75	762	56	763	16′13″	197″
...	15·35	1,691	...	711	...	751	...	...
1,052	17·5	1,780	75·4	730	56·8	802	15′52″	220″
1,009	18·4	1,885	78·8	724	58·7	756	15′12″	208″
1,055	17·1	1,805	74·5	735	51·6	700	17′24″	220″
...	17·65	1,820	...	728	...	752	...	...
1,092	16·6	1,800	79·2	785	57·2	776	14′57″	212″
1,206	17·4	1,960	78·2	830	52·7	716	17′ 1″	231″
...	17	1,880	...	807·5	...	746	...	...
1,056	19·5	1,975	82·2	819	58·1	735	15′55″	212″
994	17·9	1,700	79·2	790	50	725	17′12″	219″
1,002	18·5	1,700	80·4	812	55·6	755	16′19″	217″
...	18·65	1,790	...	809	...	738	...	...
...	17·86	1,825	...	778·1	...	745·6	...	...

Table II. **Train n° 115 from**

TYPE DER LOCOMOTIVE.	Date of trial.	State of weather.	Load ha at tend drawh in to
1. — Type 35 without superheater	18 April 1906.	Rain and wind.	331
	20 — —	Fine weather.	329
	23 — —	Dry weather. Strong side wind.	296
	27 — —	Fine weather.	336
	30 — —	— —	338
	4 May —	— —	329
	29 — —	Dry weather. Wind.	298
Average.	...	...	...
2. — Type 35 with superheater	19 April 1906.	Wind. Rails damp.	333
	21 — —	Fine weather.	332
	24 — —	Rain and wind.	327
	28 — —	Fine weather.	337
	1 May —	— —	321
	5 — —	— —	330
	26 — —	— —	336
Average.	...	...	...
3. — Type 8 with fixed exhaust and Serve tubes	9 May 1906.	Fine weather.	328
	11 June —	— —	301
	16 — —	Dry weather.	356
Average.	...	...	...
4. — Type 8 with fixed exhaust and smooth tubes	28 May 1906.	Fine weather.	299
	13 June —	— —	294
Average.	...	...	...
5. — Type 8 with variable exhaust and Serve tubes.	12 June 1906.	Fine weather.	323
	15 — —	Dry weather.	297
	18 — —	Fine weather.	313
Average.	...	...	...
Average, type 8.	...	...	...

xelles-Midi (75 kilometres). **Table II.**

Consumption				Section where the locomotive developed most power, between kilometre-marks 57-50 (+ 4 millimetres)		Actual times of running, from passing Mons till passing Braine-le-Comte. — Time specified : 29 minutes.
per journey.		Per horsepower-hour (270,000 kilogrammetres at the tender drawhook).				
er, n rams.	Briquettes, in kilograms.	Water, in kilograms.	Briquettes, in kilograms.	Mean speed recorded, in kilometres per hour.	Mean power developed at drawhook of tender, in horse-power.	
400	1,091	21·6	2,820	57·8	562	31'47"
250	1,030	22·5	2,770	63·6	638	26'45"
920	1,138	23·2	2,980	61·9	665	23'24"
200	1,088	22·2	2,620	60·7	600	27'56"
000	1,113	23·1	2,550	62·2	606	27' 1"
500	1,103	25·2	2,920	64·5	—	25'50"
400	968	—	—	64·2	582	25'18"
.	...	22·98	2,778	...	609	...
850	938	15·6	2,130	73·1	746	24'55"
800	915	16·4	2,210	68·5	708	24'30"
950	800	16·2	1,870	69·5	700	24'24"
300	900	14·9	1,840	72·4	770	—
600	822	16·8	1,810	—	—	—
600	873	—	—	70·7	—	24'52"
100	786	17·2	1,920	72·1	715	24'27"
.	...	16·19	1,965	...	728	...
500	816	19·7	1,890	73·1	773	23'46"
700	807	20·3	2,100	—	—	—
400	835	19·5	1,930	72·5	758	24' 8"
.	...	19·8	1,970	...	765	...
400	810	20·2	2,250	—	—	—
950	767	21·4	2,370	72·5	645	25'13"
.	...	20·8.	2,310	...	645	...
450	831	20·4	2,280	—	—	—
700	840	21·1	2,312	76·2	782	23'12"
150	827	—	—	76·5	810	25'24"
..	...	20·7	2,296	...	796	...
..	...	20·4	2,162	...	735	...

Table III. — Summary.

TYPE OF LOCOMOTIVE.	Number of runs from which the averages were determined.	Average consumption per horsepower-hour, measured at drawhook of tender.				Average power, measured at tender drawhook, on the sectio where the locomotives developed the maximum power.			
		Water.		Briquettes.		Between kilometres 21 and 25 (ascent, 5 per mil).		Between kilometr 245 and 236 (ascent, 8 per mil	
		Kilograms.	Economy as compared with locomotive type 35 without superheater, per cent.	Kilograms.	Economy as compared with locomotive type 35 without superheater, per cent.	Horse-power.	Increased power as compared with locomotive type 35 without superheater, per cent.	Horse-power.	Increased power as compared with locomotive type 35 without superheater
Train No. 122 from Bruxelles-Midi to Feignies (79 kilometres).									
Type 35 without superheater . . .	7	21·48	...	2,502	...	616	...	672	...
Type 35 with superheater	5	15·35	28·5	1,691	32·3	711	15·2	751	11·8
Type 8. Serve tubes. Fixed exhaust. . . .	3	17·65	17·9	1,820	27·3	728	18·0	752	12·0
Type 8. Serve tubes. Variable exhaust. . .	3	18·65	13·3	1,790	28·3	809	31·2	738	9·9
Type 8. Smooth tubes: fixed exhaust. .	2	17·00	20·86	1,880	24·86	807·5	31·0	746	11·0
Type 8; average for the three locomotives.	8	17·86	16·85	1,825	27	778·1	26·31	745·6	10·95
Train No. 115 from Quévy to Bruxelles-Midi (75 kilometres).									
						Between kilometres 57 and 50 (ascent, 4 per mil).			
Type 35 without superheater . . .	6	22·98	...	2,778	...	609	...	...	...
Type 35 with superheater	6	16·19	29·5	1,965	29·2	728	19·5	...	...
Type 8. Serve tubes. Fixed exhaust. . . .	3	19·8	14·9	1,970	29·0	765	25·5	...	...
Type 8. Serve tubes. Variable exhaust. . .	3	20·7	8·9	2,296	17·5	796	30.5	...	...
Type 8. Smooth tubes: fixed exhaust. .	2	20·8	9·48	2,310	16·84	645	6·0	...	...
Type 8; average for the three locomotives.	8	20·4	11·22	2,162	22·17	735	20·68	...	...

General summary.

TYPE OF LOCOMOTIVE.	Number of runs from which the averages were determined.	Average consumption per horsepower-hour, measured at drawhook of tender.			
		Water.		Briquettes.	
		Kilograms.	Economy as compared with locomotive type 35 without superheater, per cent.	Kilograms.	Economy as compared w locomotive type 35 witho superheater, per cent.
Type 35 without superheater	13	22·15	...	2,614	...
Type 35 with superheater	11	15·80	28·67	1,839	29·64
Type 8.	16	19·03	14·00	1,982	24·17

The trials were carried out on the Brussels-Liége (100 kilometres [62 miles] with express trains during the Brussels-Ans (94 kilometres [58·4 miles]) run in 83 minutes without stop and the Ans-Brussels run in 75 minutes without stop.

The Brussels-Liége line includes 10 kilometres (6·2 miles) of a continuous 5 per mil ascent between Brussels and Louvain; from Louvain to Ans (64 kilometres [39·8 miles]) there is practically a continuous ascent, varying from 2 to 5 per mil. The results of the trials are given in the annexed tables IV to VI.

The saving per horse-power, measured at the drawbar, given by the superheated-steam locomotive of type 18, as compared with the compound, amounted to 19·52 per cent of coal and 23·27 per cent of water. In considering these results, it is to be noted, firstly, that the difference between the weights of the two locomotives, amounting to 19·35 tons (19·04 English tons), is in favour of type 18; secondly, that there was a difference between the mean weight of the trains, those hauled by type 18 being about 20 tons lighter than those hauled by the Atlantic, the two locomotives having been loaded as far as possible proportionately to their powers; and thirdly, the short run (100 kilometres [62 miles]), which is particularly favourable to a locomotive with a small fire-box.

As compared with the similar locomotive without superheater, type 18 has hauled, while observing the same time-table, from 30 to 33 tons more, which corresponds to 10 or 12 per cent of load.

Results of comparative trials with an « Atlantic » compound without superheater and a locomotive with six coupled wheels, four equal cylinders, and using superheated steam. — The following are the chief particulars of these locomotives :

—	*Atlantic* type.	Type with four equal cylinders and with superheater.
Number of wheels	4-4-2	4-6-0
Diameter of driving wheels, in metres	1·98	1·98
Diameter of cylinders, in metres	0·36 high-pressure. 0·60 low-pressure.	0·435 (1)
Length of stroke of piston, in metres	0·64	0·61
Working pressure, in atmospheres	15·5	14
Grate area, in square metres	3·03	3·01
Direct heating surface, in square metres	16·17	15·44
Heating surface inside the tubes, in square metres	218·81 Serve tubes	138·87
Superheating surface, external, in square metres	...	37·80
Weight empty, in kilograms	68,103	76,000 (1)
Weight in working order, in kilograms	74,500	84,300
Adhesive weight in kilograms	36,900	54,900

(1) The forty locomotives of this type ordered in 1908 have the diameter of their cylinders increased to 0·445 metre and their total weight empty, is about 73 tons.

The trials were made on the Brussels-Liége (100 kilometres [62 miles]) and Brussels-Ostend (122 kilometres [75·8 miles]) lines, with express trains doing the

Table IV. — Train No. 686 from Bruxelles-Nord to Liége.

TYPE OF LOCOMOTIVE.	Date of trial.	Load hauled at tender drawhook in tons.	State of weather.	Mean power developed at tender drawhook, in horsepower.	Consumption per journey. Water, in kilograms.	Consumption per journey. Briquettes, in kilograms.	Consumption per horse-power (270,000 kilogr.-metres measured at the tender drawhook). Water, in kilograms.	Consumption per horse-power (270,000 kilogr.-metres measured at the tender drawhook). Briquettes, in kilograms.	Sections where the locomotives develop the most power. Between kilometres 8 and 12 (ascent, 5 per mil). Mean speed recorded, in kilometres per hour.	Between kilometres 8 and 12 (ascent, 5 per mil). Mean power at tender drawhook, in horse-power.	Between kilometres 78 and 84 (ascent, 4 per mil). Mean speed recorded, in kilometres per hour.	Between kilometres 78 and 84 (ascent, 4 per mil). Mean power at tender drawhook, in horse-power.	Between kilometres 96 and 102 (ascent, 4 per mil). Mean speed recorded, in kilometres per hour.	Between kilometres 96 and 102 (ascent, 4 per mil). Mean power at tender drawhook, in horse-power.	*Remarks.*
1. — *Atlantic* type. . . .	1907.														
	13 February	319·2	Wind.	528	14,875	2,290	18·40	2·84	68	768	60	613	68	740	Locomotive washed the night before.
	18 —	333·2	Calm, foggy.	523	15,925	2,331	20	2·93	61·4	682	63	670	72·4	811	Locomotive washed the night before.
	19 —	333·5	Fine.	548	15,050	2,166	19·20	2·76	65	714	65·6	704	76	795	
	26 —	332·5	Calm, foggy.	552	13,200	1,985	17·30	2·60	67·5	720	75·2	806	82	766	
Average. . .	...	329·6	...	538	...	...	18·70	2·78	...	722	...	700	...	778	
2. — Type 18 with superheater	4 February	302·7	Calm, foggy.	540	10,850	1,850	15	2·35	67·2	685	73	741	78·3	715	
	11 —	319·3	Wind, frost.	575	11,400	2,144	13·05	2·46	63·6	686	68·8	766	Stop.	Stop.	Locomotive washed the night before.
	12 —	313	—	601	12,125	2,029	13·40	2·28	61·2	665	63	690	72	788	
	20 —	310·8	Favourable wind.	532	12,050	1,894	14·90	2·35	69	680	69·6	745	73	691	Locomotive washed the night before.
Average. . .	...	311·4	...	562	...	...	14·10	2·36	...	679	...	738	...	731	

Table V. — Train No. 585 from Liége to Bruxelles-Nord.

TYPE OF LOCOMOTIVE.	Date of trial, year 1907.	Load hauled at tender drawhook, in tons.	State of weather.	Mean power developed at tender drawhook, in horse-power.	Consumption per journey.		Consumption per horse power (270,000 kilogram-metres measured at the tender drawhook).		Speed between kilometres 97 and 86, in kilometres per hour.
					Water, in kilograms.	Briquettes, in kilograms.	Water, in kilograms.	Briquettes, in kilograms.	
1. — *Atlantic* type	13 Febr.	360·2	Wind, foggy.	438	13,050	1,849	22·4	3·18	97
	18 —	356·2	Wind.	475	13,575	2,060	21·2	3·21	96
	19 —	370·7	Wind.	538	15,200	2,176	20·9	3·00	98
	26 —	344·0	Fine.	432	11,400	1,668	19·5	2·85	106
Average. . .	...	357·7	...	471	...	...	21·0	3·06	...
2. — Type 18 with superheater	4 Febr.	305·0	Dry, frost.	416	9,700	1,450	18·2	2·71	97
	11 —	338·0	Wind, rain.	472	10,600	1,493	15·4	2·17	89
	12 —	352·1	Wind, frost.	532	10,925	1,500	17·6	2·30	93
	20 —	348·2	Violent wind.	520	11,300	1,703	14·3	2·18	90
Average. . .	...	335·8	...	485	...	...	16·4	2·34	...

Table VI. — Summary.

TYPE OF LOCOMOTIVE.	Number of runs.	Mean power developed at tender drawhook, in horse-power.	Average consumption per journey.		Average consumption per horse-power (270,000 kilogram-metres measured at the tender drawhook).	
			Water, in kilograms.	Briquettes, in kilograms.	Water, in kilograms.	Briquettes, in kilograms.
Atlantic type	8	504	14,034	2,066	19·85	2·92
Type 18 with superheater.	8	524	11,119	1,765	15·23	2·35

run from Brussels to Ostend and vice versa with one intermediate stop at Gand-Saint-Pierre. The Brussels-Liége trains were those used for the preceding experiments.

The Brussels-Ostend line is level.

As has been stated above, the Brussels-Liége line includes 10 kilometres (6·2 miles) of continuous ascent of 5 per mil between Brussels and Louvain. From Louvain to Ans (64 kilometres [39·8 miles]) there is a nearly continuous rise, varying between 2 to 5 per mil.

As in the preceding experiments, the dynamometer car was placed immediately next the tender; the fuel consisted exclusively of briquettes of the same quality and the consumptions given in the annexed tables VII and VIII are the results obtained.

The tables VII and VIII lead to the conclusion that superheating as compared with compounding results in a mean economy of 9 per cent of water and of 12·3 per cent of fuel; moreover the mean speed of the superheated-steam locomotive was 5 per cent greater than that of the compound.

The trials have also demonstrated the superiority of the locomotive with four equal cylinders in the following respects : it is easier to drive; one single mechanism operates the four valves and at starting the full pressure is at once applied to the four pistons without any necessity for operating a special starting valve; 2° greater stability at high speeds, resulting partly from the equal distribution of the work in the cylinders.

Results obtained in current service with superheated-steam locomotives. — The statistics kept of the mileage and of the consumptions of locomotives for the years 1906, 1907 and the first half of 1908 show the consumption of coal and oil per kilometre, both for the superheated-steam locomotive and the saturated-steam locomotives which have been doing the same work, that is to say have hauled the same trains under absolutely the same conditions. The results are given in the annexed table IX. The different kinds of fuel have been converted into free-burning small coal according to a scale of prices; the consumptions given represent the coal taken from store, that is to say not only the coal burnt on the journey, but also all the indirect consumptions which are connected with lighting the fires, with the cleaning and with keeping up the fire during stops and with running with regulator closed, on none of which superheating has any influence. These latter represent about 40 per cent of the total consumption; when we find in the table that in current service locomotives of type 32, with superheaters, belonging to Antwerp-North, have shown as compared with similar locomotives without superheaters a saving in coal of 18·92 per cent. we can conclude that while running the actual saving has been $\frac{18{\cdot}92 \times 100}{60} = 31{\cdot}5$ per cent.

Similar information is given (table X) with regard to the work of superhead-steam locomotives and of compound locomotives of the same age, which during 1906 and 1907 were used for the same services, hauling alternately the same trains.

Table VII. — Trials (1) of the locomotive type 9 (with four equal cylinders and Schmidt superheater).

Date of trial.	RUN.	Total weight of train, locomotive and tender included, in tons.	Work, in kilogrammetres.	Works.			Consumption.		Consumption per 10,000 Kilogrammetres.		*Remarks.*
				Work absorbed in braking, in Kilogrammetres.	Total work of steam, in Kilogrammetres.	Total work at drawhook, in Kilogrammetres.	Coal, in Kilograms.	Water, in Kilograms.	Coal λ (column 8 divided by column 6, in grams.	Water μ (when 9 divided by column 6), in grams.	
1	2	3	4	5	6	7	8	9	10	11	12
1907.											
22 Aug.	Brussels-Liége. . . .	454	329	92,748	381,070,000	211,500,000	1,801	11,575	47.4	304	
22 —	Liége-Brussels. . . .	409	284	181,770	279,840,000	147,130,000	1,213	10,600	43.3	379	
23 —	Brussels-Liége. . . .	475	350	85,650	286,400,000	224,000,000	1,466	11,175	51	390	
23 —	Liége-Brussels. . . .	414	290	123,120	254,510,000	150,700,000	1,226	10,675	44	380	
27 —	Brussels-Liége. . . .	494	368.6	89,410	360,800,000	239,920,000	1,883	12,125	52	336	
27 —	Liége-Brussels. . . .	414	289.5	130,320	307,944,840	140,500,000	1,259	10,150	40.8	329	
28 —	Liége-Brussels. . .	415	290	133,200	293,328,600	114,800,000	1,115	9,750	38	332	
30 —	Brussels-Ostend . . .	463	338.3	171,050	414,100,000	231,580,000	1,888	12,500	45.6	302	
30 Nov.	Ostend-Brussels . . .	445	321	115,700	360,900,000	197,340,000	1,453	11,400	40	317	
27 —	Liége-Brussels. . . .	318	198	115,900	258,242,000	111,800,000	1,144	9,100	44	352	
27 —	Brussels-Liége. . . .	448	324	98,400	378,710,000	237,930,000	2,044	12,825	54	339	
28 —	Liége-Brussels. . . .	327	204	164,200	237,763,000	92,770,000	1,170	9,225	49	389	Steam heating.
3 Dec.	Brussels-Ostend . . .	433	309	133,800	406,450,000	222,800,000	2,099	13,575	51.6	334	— —
3 ·	Ostend-Brussels . . .	316	122	152,900	291,640,000	130,710,000	1,455	12,250	49.9	420	— —
Mean of fourteen trials		...	...	...	...	...	...	...	46.5	350	

(1) Trials carried out by Messrs. Huberti and Doyen.

Table VIII. — Trials (1) of the locomotive, type « Atlantic ».

Date of trial	RUN.	Total weight of train, locomotive and tender included, in tons.	Work, in kilogrammetres.	Works.			Consumption.		Consumption per 10,000 kilogrammetres.		*Remarks.*
				Work absorbed in braking, in kilogrammetres.	Total work of steam, in kilogrammetres.	Total work at drawhook, in kilogrammetres.	Coal, in kilograms.	Water, in kilograms.	Coal λ (column 8 divided by column 6), in grams.	Water μ (when 9 divided by column 6), in grams.	
1	2	3	4	5	6	7	8	9	10	11	12
1907.											
5 Sept.	Brussels-Liége.	479	364	50,100	379,400,000	245,800,000	2,015	14,750	54·8	389	
6 —	Brussels-Liége.	478	362	84,130	381,160,000	245,500,000	2,055	14,900	53·9	399	
6 —	Liége-Brussels.	403	289.6	142,430	282,802,000	142,890,000	1,530	11,850	54	419	No wind. Rails good.
12 —	Brussels-Ostend	443.9	328.8	234,750	443,700,000	236,110,000	2,066	15,150	46·6	342	Fine weather.
12 —	Ostend-Brussels	397.3	282.6	175,510	354,000,000	186,300,000	1,800	12,150	51	343	Fine weather. Dry.
13 —	Brussels-Ostend	492.2	376.8	99,931	395,900,000	256,707,000	2,026	14,850	51	375	— — —
13 —	Ostend-Brussels	428.6	314.7	156,500	373,430,000	208,260,000	1,810	13,400	48	359	— — —
25 Nov.	Brussels-Liége.	449	334	50,730	408,700,000	282,336,500	2,400	16,850	58·7	412	Gale. Skidding.
25 —	Liége-Brussels.	328	213	101,100	247,253,000	125,580,000	1,447	10,375	58·5	420	Skidding.
Mean of nine trials		...	...	...	...	...	...	...	53	383	

Final results. . . . . . { Coal economy due to superheat . . . . . 12.3 p. c.
Water economy due to superheat. . . . . 9 —

(1) Trials carried out by Messrs. Huberti and Doyen.

In 1908, the superheated-steam locomotives of type 18, Brussels-North, were added to the Atlantic compound series; the compounds of type 8, Brussels-South, were placed in a special series; this also was done with most of the Schaerbeek superheated-steam locomotives of type 32.

Taking the cost of the free-burning small coal at 12 francs per ton (9s. 9d. per English ton) and after deducting the extra cost of lubrication, the superheated-steam locomotives of type, Antwerp-North, showed a saving, per 1000 kilometres run, in materials consumed (fuel and oil) of 51·75 francs (£3. 6*s.* 7·51*d.* per 1000 miles), in 1907 and of 46·47 francs (£3.1*s.* 1·38*d.* per 100 miles) in 1908; the similar Schaerbeek locomotives showed one of 45·20 francs (£2.18*s.* 2·31*d.* per 1000 miles) in 1907.

It was rational to utilize the greater power of the superheated-steam locomotives, by increasing the loads. This was done in 1908. Thus on the Ostend-Herbesthal run, the weight hauled by the superheated-steam locomotives of type 18 was increased from 300 to 335 tons in the case of the express trains; that of the suburban trains hauled by the superheated-steam locomotives of type 32 was increased between 10 and 15 per cent, according to line. As regards the goods trains hauled by superheated-steam locomotives of types 32 and 35, the limits of weight have been increased between 15 and 27 per cent.

Upkeep and repair of superheated-steam locomotives. — As regards the superheater proper, it has to be noted that quite a number of the small superheater tubes became broken at the thread entering the steel bend-connectors. In the method adopted in order to prevent such fracture, the thread does not begin flush with the surface of the connector, but only 5 millimetres ($^3/_{16}$ inch) further in (fig. 14). Brazed joints have also been tried for the same purpose.

During the five years that superheating has been in use, only small superheater tubes have had to be taken out owing to wear or cracks.

Scale deposited more or less quickly in the superheater elements; it was observed, in the case of locomotives which had been in use for three years, that the scale extended to about 2·50 metres (8 ft. 2 inch.) from the saturated-steam collector; the scale had a thickness of 4 to 6 millimetres ($^3/_{16}$ to $^1/_4$ inch) near the ends and then decreased gradually.

The superheater remains tight; the joints between the elements and the collector hold well and it is seldom necessary to take out the superheater tubes.

At first it was necessary to remake some of the joints between the collector and the tube-plate. Care must be taken during the erection that the collector is well supported on the two angle-irons riveted to the smoke-box, and a joint made with a spherical-face ring is used, so as to ensure amount of mobility to the whole installation.

The fixing of the elements in the large superheater tubes has produced, at the points of contact, perforations which were observed on locomotives which had been in use for four years; in other cases large tubes, principally of the bottom row,

Table IX. Consumptions of the superheated-steam locomotives and of the saturated-stea

Type of locomotives compared.	DEPOT.	Locomotives with superheater.					
		Number.	Distance run, in kilometres.	Coal consumption.		Cost of lubrication.	
				Total, in kilograms.	Per kilometre, in kilograms.	Total, in francs.	Per 1,000 kilometres, in francs.
	Year 1906.						
18	Verviers	2	78,072	1,324,350	16·96	2,317·64	29·68
18	Brüssel-Nord	2	89,641	1,371,750	15·30	3,216·30	35·87
32	Schaerbeek	4	149,489	2,165,475	14·48	2,886 95	19·31
32	Meirelbeke	2	40,094	587,490	14·65	759·24	18·93
35	Bruxelles-Midi	8	318,987	5,601,750	17·56	6,945·60	21·77
35	Schaerbeek	2	52,067	795,000	15·26	816·33	15·68
	Year 1907.						
18	Verviers	3	155,435	2,743,200	17·64	4,472·52	28·77
18	Brüssel-Nord	2	98,939	1,550,700	15 67	2,532·12	25·59
32	Meirelbeke	2	61,313	840,930	13·69	1,013·55	16·53
32	Antwerpen-Nord	16	438,299	9,409,235	21·46	10,192·12	23·25
32	Schaerbeek	16	612,393	9,941,805	16·23	16,666·82	27·21
35	Bruxelles-Midi	8	300,108	5,531,150	18·43	6,937·41	23·11
35	Schaerbeek	2	78,724	1,324,950	16·83	1,706·79	21·68
	First six months of 1908.						
32	Meirelbeke	2	28,445	352,470	12·39	349·50	12·28
32	Antwerpen-Nord	27	338,249	7,751,645	22·91	7,319·35	21·63
35	Bruxelles-Midi	8	159,236	3,336,900	20·95	4,253·96	26·71
35	Schaerbeek	2	34,454	589,200	17·10	700·77	20·33

Table X. Consumptions of the superheated-steam locomotives and of the saturated-stear

DEPOT.	Locomotives with superheater.						
	Type.	Number.	Distance, run, in kilometres.	Coal consumption.		Cost of lubrication.	
				Total, in kilograms.	Per kilometre, in kilograms.	Total, in francs.	Per 1,000 kilometres, in francs.
		Year 1906.					
Bruxelles-Midi	35	6	250,423	4,333,500	17·30	5,691·78	22·73
		Year 1907.					
Bruxelles-Midi	35	6	165,959	3,084,800	18·58	3,938·01	23·72

tives of the same type working under absolutely identical conditions (same series). **Table IX.**

Distance run, in kilometres.	Locomotive with superheater. Coal consumption. Total, in kilograms.	Coal consumption. Per kilometre, in kilograms.	Cost of lubrication. Total, in francs.	Cost of lubrication. Per 1,000 kilometres, in francs.	Economy of fuel resulting from superheating. in kilograms.	Economy of fuel resulting from superheating. per cent.	Extra cost of lubrication of locomotives with superheater. Per 1,000 kilometres, in francs.	Extra cost of lubrication of locomotives with superheater. Per cent.
Year 1906.								
938,099	18,046,500	19·23	15,980·36	16·97	2·27	11·80	12·71	74·89
673,465	11,851,200	17·59	21,231·04	31·67	2·29	13·01	4·20	13·26
1,624,442	31,153,100	19·17	19,721·15	12·14	4·69	24·46	7·17	59·06
353,306	6,608,925	18·70	5,212·49	14·75	4·05	21·65	4·18	28·33
363,663	8,100,000	22·27	8,065·76	22·17	4·71	21·14	— 0·40	— 1·80
404,515	7,974,375	19·71	6,625·77	16·37	4·45	22·57	— 0·69	— 4·21
Year 1907.								
727,989	14,373,150	19·74	14,687·32	20·17	2·10	10·63	8·60	42·63
413,507	7,178,700	17·36	11,339·67	27·42	1·69	9·73	— 1·83	— 6·67
379,933	6,026,610	15·86	5,406·31	14·22	2·17	13·68	2·31	16·24
1,329,489	35,198,550	26·47	20,060·20	15·08	5·01	18·92	8·17	54·17
2,242,359	47,246,645	21·07	32,357·92	14·43	4·84	22·97	12·78	88·56
335,007	7,902,400	23·58	7,911·66	23·61	5·15	21·84	— 0·50	— 2·11
329,112	6,859,800	20·84	7,597·47	23·08	4·01	19·24	— 1·40	— 6·06
First six months of 1908.								
229,424	4,013,100	17·49	3,267·20	14·24	5·10	29·15	— 1·96	— 13·76
559,152	15,300,710	27·36	8,241·40	14·70	4·45	16·26	6·93	47·14
163,577	4,316,400	26·38	4,048·60	24·75	5·43	20·58	1·96	7·91
158,203	3,350,400	21·17	1,817·36	11·48	4·07	19·22	8·85	77·09

otives of the same type working under absolutely identical conditions (same series). **Table X.**

Number.	Distance run, in kilometres.	Locomotive with superheater. Coal consumption. Total, in kilograms.	Coal consumption. Per kilometre, in kilograms.	Cost of lubrication. Total, in francs.	Cost of lubrication. Per 1,000 kilometres, in francs.	Economy of fuel resulting from superheating. in kilograms.	Economy of fuel resulting from superheating. per cent.	Extra cost of lubrication of locomotives with superheater. Per 1,000 kilometres, in francs.	Extra cost of lubrication of locomotives with superheater. Per cent.
Year 1906.									
5	193,693	3,524,250	18·19	4,177·95	21·57	0·89	4·89	1·16	5·37
Year 1907.									
5	172,733	3,437,250	19·89	3,812·82	22·07	1·31	6·58	1·65	7·47

were replaced after having been expanded several times. The number of large tubes replaced up to 1 April 1907 amounts to 98. The method of fixing shown in figure 2 has been adopted in order to obtain better tightness.

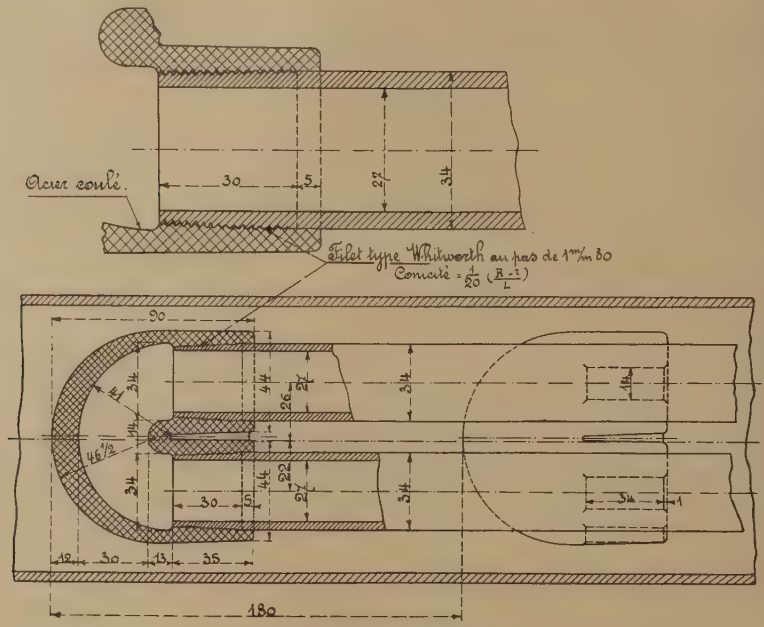

Fig. 14. — Belgian State Railway.

Explanation of French terms : Acier coulé = Steel casting.
Filet type Whitworth au pas 1 m/m 80 = Whitworth thread, 14 to the inch. — Conicité = Taper.

In the case of a few locomotives, it was observed that the fire-box tube-plate had become very slightly deformed, between the bottom row of the large tubes and the top row of the small tubes. That part of the plate which is between the two rows had become bent towards the back : the deformation amounted to from 2 to 4 millimetres ($^3/_{32}$ to $^3/_{16}$ inch) at the middle and tapered off to nothing towards either side.

The parts in contact with the superheated steam were, when superheated steam was first used, liable to damage, such as seizing and even the fracture of cylinders; pistons became loosened and then broken. This was chiefly due to want of sufficient play between the piston and the cylinder, producing an amount of friction which was not always appreciated at the locomotive sheds. These difficulties, inherent in any innovation, were only transient, and now cylinders, pistons and valve gear act as with saturated steam.

The tightness of the valves of the locomotive with four equal cylinders has been checked and found perfect after running 47,000 kilometres (29,200 miles); only a wear of 0·4 millimetre ($^{1}/_{64}$ inch) has been found in the liner, which is compensated by the springing of the rings.

As regards the fractures of top and bottom covers of cylinders in consequence of water-hammer action at the start, matters have become normal now that the diameter of the safety valves has been increased to 0·10 metre ($3\ ^{15}/_{16}$ inches).

The tightness of the stuffing boxes has been materially improved by the means already described. As regards more especially leakages along the piston rod, it is very important to use oil of good quality. The piston rod must be kept greasy; the thin film of oil between the white metal of the box and the rod acts as an insulating layer. Cheap oils result in quick wear of the rings owing to the small lubricating power they possess and leaks are soon produced. Sometimes even the rods become hot and blue, the white metal of the box softens and melts.

Moreover there is no advantage in using oils with a lower flash-point; their greater consumption more than outweighs their lower price and the rubbing surfaces become worn much more quickly. The Belgian State Railway has made numerous unsuccessful attempts to obtain a cheap oil; but in each case leaks again occurred in the stuffing boxes and pistons jammed in the cylinders, so that locomotives were laid up at the sheds. Moreover, deposits of carbonized oil were observed, obstructing to a greater or less extent the superheater elements at their points of junction with the superheated-steam collector; these obstructions were attributed to the use of oil of too low a flash-point and also to an excessive supply. Oil crusts of the same kind were found inside the pipes supplying the steam as well as on the bottoms of the cylinders and the bodies of the pistons and valves, filling the circular grooves and the holes in the rings.

The spherical rings of the glands which allow for the lateral displacement of the rods must, in order to be tight, be very accurate fits, seeing the great fluidity of the superheated steam; grinding them true is a difficult and troublesome job.

On 31 December 1906, the stock included 56 superheated-steam locomotives. If we deduct the locomotives which began running in December, we have 47 superheated-steam locomotives used in the year 1906, which ran altogether 1,038,519 kilometres (645,317 miles). The work of upkeep and repair resulting from the superheating and carried out at the sheds, on the superheater, the damper, the pistons, the cylinders, the valve gear and the stuffing boxes resulted for all these 47 locomotives in a total laying-up time of 372 days, or one day per 2,800 kilometres (1,740 miles). Of these 372 days, 228 were devoted to the piston-rod stuffing boxes. In 1907, these same 47 locomotives ran 1,703,964 kilometres (1,058,813 miles), and the laying-up time (resulting from the superheating) was 522 days, or one day per 3,450 kilometres (2,144 miles) run. Piston-rod stuffing boxes again account for the greater part, namely 301 days.

During the first six months of 1908, the laying-up resulting from the super-

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heating, was 251 days for the 47 locomotives which we are considering, 115 days of them being due to stuffing boxes.

The improvement is evident; it results essentially from the improvements in the packing and the more extended use of oil of best quality. Of the 47 locomotives in question, there are eight which during the years 1906, 1907 and the first six months of 1908 were not laid up one single day on account of the superheating; the minor maintenance could be attended to between working hours.

It cannot be denied that the superheated-steam locomotive costs more for upkeep and is laid up more; but this is counter-balanced in part in the case of single-expansion engines by a lower working pressure, which improves the life of the boilers, by the less frequent washing out of the latter, by the possibility up to a certain point, of using engines with two equal cylinders for services otherwise requiring four-cylinder locomotives, which are necessarily heavier and more expensive.

SPAIN.

Spanish Northern Railway.

A goods locomotive with eight coupled wheels was fitted with a Pielock superheater in 1907.

Piston valves with springs are used. The piston rings and the front and back stuffing boxes of the piston rods are of the pattern adopted by Mr. Schmidt.

The ends of the cylinders have safety valves 32 millimetres in diameter fitted to them.

The diameter of the cylinders has been increased 6 per cent as compared with similar locomotives without superheaters.

The heating surface of the superheater is 19·30 square metres (207·75 square feet), corresponding to 11·95 per cent of the total heating surface (161·33 square metres [1,736·60 square feet]).

At the start, the superheat is 15° C. (27° Fahr.); it reaches 60° C. (108° Fahr.) after running 3 kilometres (1·86 miles) and does not exceed the latter figure when a goods train is hauled. The trials are not sufficiently advanced to enable the railway to supply any information on the subject of economy, extra power, etc.

Mechanically-operated lubricators are used; special oil having a high flash-point is used. The cost of lubrication is not increased as compared with that of saturated-steam locomotives.

The expanding of the tubes so as to prevent leakage presents difficulties.

The company states that 69 superheated-steam locomotives are being built, but the type of superheater is not specified.

FRANCE.

French Eastern Railway.

The French Eastern Railway has quite recently equipped four compound express four-cylinder locomotives with Schmidt superheaters; it is also fitting them to two other two-cylinder compounds. It is also going to make a trial, on two locomotives, of a device it has worked out and which is intended to superheat the steam in the intermediate receiver.

The company has not yet obtained any results with these superheaters and is merely going to make experiments.

The superheater is of the pattern with a quadruple passage of the steam between the tube-plates; the high-pressure steam alone is superheated. It presents no new feature; it has however to be mentioned that in order to avoid the fractures of tubes forming the elements at their point of junction with the bend connectors, the threaded part of the latter is continued by a smooth part into which the tube enters in such a way as to protect the threads against the gases coming from the fire-box, and against the deposit of cinders and of damp which would produce corrosion.

The end of the superheater elements is 0·70 metre (2 ft. $3\,^{9}/_{16}$ in.) from the fire-box tube-plate.

The pistons, the piston-rod and the valve-rod stuffing boxes are of the Schmidt pattern.

The low-pressures cylinders and valve gear have not been modified in any way; the pistons and stuffing boxes are like those of similar locomotives using saturated steam.

The lubrication of the cylinders is effected by a Bourdon mechanical lubricator and an auxiliary Friedman lubricator.

The pyrometer is of the Fournier type.

The working pressure has been reduced from 15 to 13 kilograms per square centimetre (213·34 to 184·90 lb. per square inch) in the case of the two-cylinder compounds as well as of those which are fitted with the superheater for the low-pressure steam.

As for the cylinders, their diameters have been increased in order to allow for the increased volume resulting from the use of superheated steam and the reduction in the working pressure; in the case of the four-cylinder compounds, the diameter of the high-pressure cylinders of these two locomotives has been increased from 360 to 390 millimetres (1 ft. $2\,^{3}/_{16}$ in. to 1 ft. $3\,^{3}/_{8}$ in.).

The chief particulars of the two types of locomotives which have been equipped with the Schmidt superheaters are given in the following table :

—	Four-cylinder compound.	Two-cylinder compound.
Large tubes, 116 by 125 (3 rows) number	21	18
Diameter of steel superheater tubes, in millimetres	27 × 34	27 × 34
External superheating surface, in square metres	35·85	29·09
Grate area, in square metres	...	2·06
Total heating surface, in square metres	157·64	104·59
Working pressure, in kilograms per square centimetre	...	13
Diameter of high-pressure cylinder, in metres	0·36 et 0·39	0·45
Diameter of low-pressure cylinder, in metres	0·59	0·65
Stroke of piston, in metres	0·68	0·68
Diameter of high-pressure piston valve, in metres	0·25	0·22
Diameter of low-pressure piston valve in metres	0·35	0·30
Diameter of driving wheels	2·09	1·42
Type of locomotive	4-6-0	2-6-0

The application of a helicoid superheater to the steam of the intermediate receiver of two compound two-cylinder locomotives was effected to dry the high-pressure exhaust steam charged with moisture at a comparatively low pressure and temperature, and to superheat it to a temperature equal to or slightly higher than that of the steam admitted to the high-pressure cylinder (say about 200° C. [392° Fahr.]), so as to avoid having in these locomotives the special devices made necessary by using a superheater by the Schmidt type, such as special lubricators and oils, stuffing boxes, appropriate cylinder and piston valve covers, etc.; these different appliances remain of the same type as in the locomotives of the same series not equipped with superheaters.

This result can be attained by a single horizontal row of superheater elements; this simplifies as much as possible the importance of the parts placed in the smoke-box and moreover makes it possible to leave enough of the nest of smoke tubes, utilized for the evaporation, available while getting up steam or running with regulator closed, so that the evaporation may go on, during those periods, under conditions very much the same as in the case of other locomotives.

The nest of tubes includes six large steel tubes, with an external diameter of 133 millimetres (5 $^1/_4$ inches) and 4 millimetres ($^5/_{32}$ inch.) thick; they are contracted twice at their back ends.

The authorized pressure of the boiler has been reduced from 16 to 14 kilograms per square centimetre (227·37 to 119·12 lb. per square inch), and the working pressure from 15 to 13 kilograms per square centimetre (213·34 to 184·90 lb. per square inch.).

The superheater consists of three distinct parts : the collector, the superheater elements and the damper.

The cast-iron collector (fig. 15) is placed inside the smoke-box, against the top of the tube-plate. It consists of two large bends placed close to each other; the front one receives the saturated steam coming from the high-pressure exhaust, while the back one receives the superheated steam, coming out of the superheater elements, for the low-pressure cylinder. Two triangular flanges, at the front wall of the collector and each communicating with the respective bends, receive the tubes which connect the cylinders and the superheater.

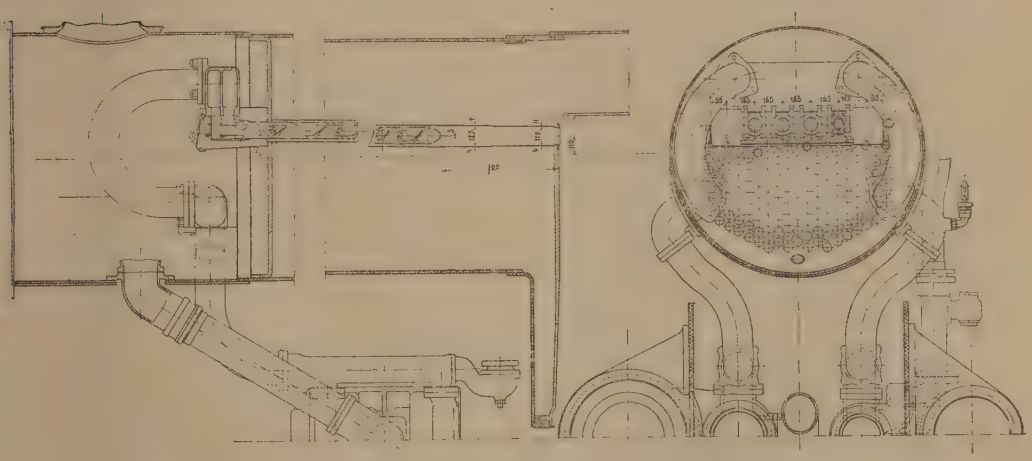

Fig. 15. — French Eastern Railway.
Helicoid superheater for the steam of the intermediate receiver of a compound locomotive with two cylinders.

The lower horizontal wall of the collector, suitably stiffened, has rectangular orifices for connecting the collector and the elements, as well as slots of trapezoidal section to take the heads of the bolts used for connecting the elements.

This collector, which has a very simple framing, is bolted at its two ends to steel brackets in the smoke-box.

There are six of these superheater elements, which are quite independent of each other; they are arranged in one horizontal row inside the large smoke tubes which have an internal diameter of 125 millimetres ($4\,^{15}/_{16}$ inches). Each element extends

to within 0·70 metre (2 ft. 3 $^{9}/_{16}$ in.) of the fire-box and consists of three separate parts :

1° An outer tube with an external diameter of 103 millimetres (4 $^{1}/_{16}$ inches), 3 millimetres ($^{3}/_{16}$ inch) thick; the one end, on the fire-box side, is closed in such a way as to present a bottom of ovoid shape, with projections outside so as to centre it; the other end is screwed to a taper connector;

2° A second tube having an external diameter of 57 millimetres (2 $^{1}/_{4}$ inches) and 2·5 millimetres ($^{3}/_{32}$ inch) thick, placed inside the former and centered by a helical strip brazed on to it;

3° A steel head, including; at the back, a conical bearing which is fixed by four bolts to the connector screwed to the outer tube, at its upper end; a grooved flange for making a joint with the collector by means of copper wire; and a partition inside for dividing the head into two compartments. The inside tube is fixed into this partition by being expanded in; a screwed plug in the front of the head makes it possible to fix it.

Two bolts passing through outer wings and sliding in the grooves of the collector are used to fix an element to the collector and to tighten up the joint.

The wet steam, passing through the exhaust high-pressure pipe into the front compartment of the collector, passes through the connectors into the six elements. In each of them, it flows through the inner tube up to the end which it cools, then passes through the space between the two tubes, and the helical surface, and returns to the space by a helicoid movement while flowing along the metal surfaces: that of the outer tube is heated directly by the fire-box gases and that of the inner tube is heated indirectly by contact with the outer tube.

During this movement, the inertia of the particles of steam produces close intermixture and ensures the absolute uniformity of their temperature. The steam again reaches the head and returns to the back compartment of the collector.

A drop damper operated automatically by a steam piston completes the installation.

As the steam passing through the superheater must not, when leaving the elements, exceed a temperature in the neighbourhood of 200° C. (392° Fahr.) to be determined experimentally, in order to keep the low-pressure cylinders at work properly, with the ordinary arrangements of lubrication, stuffing boxes and rings, it is necessary to stop the action of the superheater when there is a tendency to exceed that temperature. With this object in view, a Fournier temperature regulator is fitted to the pipe from the collector to the cylinder: when the maximum temperature (200° C. [392° Fahr.]) is attained, this stops the supply of steam to that cylinder and consequently the damper closes.

According to the trials made with this apparatus before putting it in, the variation in the temperatures necessary for opening or closing the damper is about 3° C. (5·4° Fahr.)

Reducing the amount of the superheat by adjusting the opening of the damper, is made easy by the design of the piston and its rod of control. By turning this rod, which forms a screw, the piston is brought nearer its seat and the length of its stroke is reduced to a corresponding extent; the length of rod threaded suffices to obtain all positions from fully closed to fully open.

The diameter of the high-pressure cylinders in increased to 445 millimetres (1 ft. 5 $^1/_2$ in.), and that of the low-pressure cylinders to 680 millimetres (2 ft. 2 $^{13}/_{16}$ in.), in order to allow for the reduction in the working pressure of the boiler and for the use of superheated steam in the low-pressure cylinders. The pistons have three rings. The safety valves at the bottom of the cylinders are adjusted to 14 kilograms (199·12 lb. per square inch) in the high-pressure cylinder and to 6·5 kilograms (92·45 lb. per square inch) in the low-pressure cylinder.

Friedmann pressure lubricators are provided for lubricating the cylinders.

The following are the chief particulars of the locomotives which have been equipped with the helicoid superheater :

Type of locomotive	2-6-0
Grate area, in square metres	2·06
Total heating surface, in square metres	117·21
External heating surface, in square metres	7·65
Working pressure, in kilograms per square centimetre	13
Diameter of driving wheels, in metres	1·42
Diameter of high-pressure cylinder, in metres	0·445
Diameter of low-pressure cylinder, in metres	0·680
Stroke of piston, in metres	0·660

French State Railway.
(System of the former French Western Railway Company.)

The French Western Railway began in 1908 to run two express locomotives, equipped with Schmidt superheaters and piston valves, and one goods locomotive equipped with Pielock superheaters and Lentz valves. This last application is too recent to make it possible to draw any conclusions. In addition the Schmidt superheater is being fitted to four tank locomotives; two of these locomotives are to have Schmidt piston valves, the two others, Lentz valves.

The superheater placed in the smoke tubes of the two compound locomotives is of the type with quadruple circulation of the steam between the regulator and the high-pressure valve chest; the ends of the tubes, bent upwards, are expanded into horizontal flanges fixed to the steam collector by vertical bolts.

The holder has at its front face three dampers operated automatically by a small auxiliary steam cylinder, and can be regulated by hand. The dampers are horizontal when fully opened; they drop downwards when the regulator is closed.

The pistons are of steel and screwed on to their rods; they have three grooved rings. Their diameter is 3 millimetres ($^1/_8$ inch) less than that of the cylinders.

The piston valves have only one wide ring with openings at the inner edges.

The stuffing boxes of the piston rods and tail rods are of the latest Schmidt pattern, with lateral displacement. White-metal rings alternate with bronze rings. The tail rods are supported by a special guide which together with the front plate forms one piece. The guides are arranged in such a way that the body of the piston is entirely supported by them and by the cross-heads, and never bears on the walls of the cylinders.

The bottom and top covers of the cylinder are fitted with safety valves having a diameter of 0·032 metre (1 $^{1}/_{4}$ inches).

Atmospheric valves are fitted to the valve chests.

The cylinders have no pipes connecting front and back.

A Fournier thermometer, of the saturated-steam type, is placed in the high-pressure valve chest, and two pressure gauges, placed in the driver's cab, show the pressure in the high-pressure and low-pressure valve chests.

The lubrication of the high-pressure cylinders and valves is effected by two mechanical lubricators of the Friedmann type placed on each side of the foot-plate and each with four pipes leading from it; the low-pressure cylinders are lubricated by means of a Galena sight-feed lubricator placed in the cab.

The mechanical lubricators are supplied with special mineral oil having the following properties : specific gravity at 15° C. (59° Fahr.) : 0·909; viscosity at 100° C. (212° Fahr.) (Engler) : 8 to 10; flash-point (open vessel) : above 360° C. (680° Fahr.). The sight-feed lubricator is supplied with ordinary oil.

The large tubes are swept out by means of a revolving jet; steam or compressed air is used.

The working pressure of the superheated-steam compound is 15 kilograms per square centimetre (213·34 lb. per square inch), as in the case of saturated steam. The diameter of the high-pressure cylinder has been increased from 0·350 to 0·380 metre (1 ft. $^{13}_{16}$ in. to 1 ft. 3 in.); that of the low-pressure cylinder remains at 0·55 metre (1 ft. 9 $^{11}/_{16}$ in.) as before.

The chief particulars of the superheated-steam and saturated-steam compound locomotives are given in the following table :

—	Compound using saturated steam.	Compound using superheater.
Working pressure of the boiler, in kilograms per square centimetre.	15	15
Diameter of the high-pressure cylinders, in metres. . . .	0·350	0·380
Diameter of the low-pressure cylinders, in metres	0·55	0·55
Stroke of pistons, in metres	0·64	0·64
Type of locomotive	2-3-0	2-3-0

—	Compound using saturated steam.	Compound using superheater.
Diameter of coupled wheels, in metres	1·94	1·94
Grate area, in square metres	2·80	2·80
Total heating surface, in square metres	206·71	153·50
Heating surface of superheater, in square metres	...	37 50
Weight empty, in tons	62·800	64·500

Only the high-pressure steam is superheated.

The superheat is nil at the start, and then gradually rises when the regulator is open. The ordinary degree of superheat is reached after running from 15 to 20 kilometres (9·3 to 12·4 miles), according to the weight of the train. The temperature of 360° C. (680° Fahr.) is not exceeded. When the pyrometer shows a tendency to rise beyond this point, the driver closes in succession the dampers of the holder. The drop of pressure between boiler and valve chest varies with the weight and the speed of the train; as a rule the high-pressure varies between 7 and 10 kilogams per square centimetre (between 99·56 and 142·23 lb. per square inch), the boiler pressure being 15 kilograms per square centimetre (213·34 lb. per square inch).

With a train weighing 360 tons, a cut-off of 50 65 and a speed of 85 to 105 kilometres (53 to 65 miles) per hour, the pyrometer reading was 350° C. (662° Fahr.) and that of the high-pressure valve chest pressure gauge 8 to 12 kilograms per square centimetre (113·78 to 170·67 lb. per square inch); at the receiver the temperature was 228° C. (442° Fahr.) and the pressure 2·70 kilograms per square centimetre (38·40 lb. per square inch). Thus the initial superheat was 350 — 174 = 176° C. (316·8° Fahr.) and 390 — 190·6 = 159·4° (286·9° Fahr.); that of the receiver was 228 — 128 = 100° C. (180° Fahr.).

The economy of fuel, realized by these two superheated-steam locomotives, was 13 to 14 per cent, and that of the water 20 per cent, as compared with two saturated-steam compounds which had hauled the same trains. The railway however remarks that these results were obtained with a selected staff on the superheated-steam locomotives, that is to say under conditions rather favourable to the superheating.

The additional power has varied between 10 and 15 per cent, according to train.

The amount of oil consumed is about 10 grams (9·08 drams per mile) of special oil, high-pressure, and 6 grams (5·45 drams per mile) of ordinary Mazouf oil, low-pressure, total 16 grams per kilometre (14·53 drams per mile), while the ordinary locomotives without superheater use 12 grams per kilometre (10·90 drams per

mile). The expenditures are 85 and 29 centimes per kilometre (1*s.* 1·13*d.* and 4·48*d.* per mile) respectively.

A very complete note on the application of superheated steam to the compound locomotives of the French Western Railway, has been published by Mr. Maurice Demoulin, engineer of that railway, in the *Revue générale des chemins de fer*, October 1908.

Midi Railway.

This railway has had the following built as an experiment :

1° Two boilers with Schmidt superheaters in the smoke tubes for the goods locomotives 2101, 2102, with eight coupled wheels and all the weight adhesive weight;

2° Five tank locomotives of series 5001, with ten coupled wheels and all the weight adhesive weight, also have been equipped with Schmidt superheaters in the smoke tubes.

In addition fifteen other locomotives of series 5001 will at once be ordered.

The superheater is of the type with quadruple circulation of the steam. The tube bringing the saturated steam enters the lower chamber; one tube of each superheater element takes steam from that chamber, while the other end is extended to the upper chamber by a piece of steel tube expanded into the hole of the lower wall and into the corresponding hole made in the middle division of the collector.

The collector is fixed to the tube-plate of the smoke-box by means of studs. In the 5001 locomotives it is also hung from the roof of the smoke-box by means of two articulated rods.

The 2101 locomotives have Lentz valves.

The 5001 locomotives have piston valves of the Schmidt type with spring rings, without steam jacket, and the steam is admitted by the inner edge.

The steel driving pistons are screwed on to their rods; they have three rings which project 1·5 millimetres ($^1/_{16}$ inch) beyond the body of the piston.

The stuffing boxes of the rods and tail rods of the driving pistons of the 5001 locomotives are of the Schmidt type, with spherical rings and springs.

The stuffing boxes of the rods of the driving pistons of the 2101 locomotives are also of the Schmidt type; but the tail rods are supported in a tail rod casing similar to that used on the superheater-steam locomotives of the Belgian State Railway.

The stuffing boxes of the rods and tail rods of the piston valves of the 5001 locomotives are of the Schmidt type, with bronze rings.

The white-metal rings of the stuffing boxes have the following composition : lead 80 per cent, antimony 20 per cent.

The cylinders have at each end a safety valve 50 millimetres (1 $^{31}_{32}$ inch) in

diameter to provide againts any water-hammer action, and also an atmospheric valve.

The 5001 locomotives have a pipe connecting the front and back of the piston; the valve which cuts off this communication is operated by a small steam engine which is operated by the movement of the regulator itself; it can also be operated by hand by means of a handle placed in the driver's cab.

The 2101 locomotives are equipped with a device which makes it possible to keep lifted the two admission valves, and thus establish a permanent communication between the two ends of the cylinder.

Mechanical lubricators of the Michalk and Friedmann types are used for lubricating the superheated-steam locomotives; the oil used is that known as "Perfection cylinder oil XXX", supplied by the Galena Oil Company.

At each of the places where superheated-steam locomotives are stabled, there is a special compressed-air jet for cleaning out the smoke tubes. This jet can be connected by means of a flexible metal pipe with an air valve on a branch from the pipe which connects the main reservoir with the driver's brake valve. It has at its end a conical nozzle with four wings which is introduced through the fire-box into the back end of the tube which requires sweeping and which encloses a valve kept normally closed by the pressure of the air. This valve opens and allows a jet of compressed air to issue when the nozzle is pressed against the tube.

The following are the chief particulars of locomotives 2101 and 5001 :

	Locomotives 2101.	*Locomotives 5001.*
Working pressure of boiler, in kilograms per square centimetre.	12	12
Heating surface, in square metres.	155·80	141·80
Superheater surface, in square metres	30·37	44·20
Grate area, in square metres	1·82	2·70
Number of coupled axles	4	5
Diameter of driving wheels, in metres	1·21	1·35
Diameter of pistons, in metres.	0·54	0·63
Stroke of pistons, in metres.	0·61	0·66
Weight empty, in kilograms	53,800	66,500
Adhesive weight, in kilograms.	60,300	86,000

As the superheated-steam locomotives have only been in use a very short time (locomotive 2102 is not even delivered), the railway has only been able to give us the following information concerning locomotive 2101.

The temperature recorded by the Steinle and Hartung mercury pyrometer in the steam chest reaches 300 to 310° C. (572 to 590° Fahr.) on gradients of 33 per mil with a train weighing 200 tons. On other sections the temperature observed was materially lower.

The temperature of 300° C. (572° Fahr.) is not attained until a distance of about 6 kilometres (3·7 miles) has been run.

French Northern Railway.

On the French Northern Railway superheating has been applied as an experiment to two goods locomotives with eight coupled wheels, one of the North Belgian system, No. 722, the other of the North French system, No. 4742.

These two locomotives were equipped with the Pielock superheater, of the ordinary type, the first in 1906, the second in 1907.

The Schmidt superheater is going to be fitted to five units of a series of suburban locomotives with six coupled wheels and two bogies.

On the locomotive of the French North system, flat slide valves without any compensating devices are used.

The locomotives of the North Belgian system has vertical valves on the Lenz system.

The superheating is moderate on the former locomotive. The superheater is 1·222 metres (4 ft. $^{1}/_{8}$ in.) from the fire-box tube-plate. It was accordingly possible to retain the slide valves which were there before the superheater was added.

The superheat is more considerable on the second locomotive; the superheater is 700 millimetres (2 ft. 3 $^{9}/_{16}$ in.) from the tube-plate. The Lentz valve has also been fitted as an experiment, at the same time as the Pielock superheater.

The pistons of the above two locomotives are the same as those of the locomotives using superheated steam; they have cast-iron rings of the ordinary type and there is no tail rod.

The stuffing boxes of the piston and valve rods of locomotive 4742 are the same as those used on saturated-steam locomotives; their white-metal rings consist of 73 per cent of lead, 12 per cent of tin and 15 per cent of antimony.

Locomotive 722 is fitted with stuffing boxes for the piston rods on the Lentz system, with cast-iron rings.

The tightness of the valve rods in their guides is ensured by circular grooves around them.

The cylinders have no pipe connecting front and back; nor are they fitted with safety valves.

The superheated-steam locomotives are lubricated by means of Mollerup mechanically-operated lubricators; the North Belgian uses special cylinder oil: the North French uses a mineral oil which has the following properties : specific gravity, 0·906; flash-point above 300° C. (572° Fahr.); viscosity at 30° C. (86° Fahr.), 47 minutes; at 50° C. (122° Fahr.), 14 minutes; at 70° C. (158° Fahr.), 4 minutes 30 seconds.

The temperature of the superheated steam is measured by means of a mercury-expansion thermometer, fixed to the regulator casing; the dial for reading it is inside the cab.

The chief particulars of the two locomotives equipped with superheaters of the

locomotives of the same type but using saturated steam are shown in the following table :

	Locomotive 4742 and locomotives of the same series.		*Locomotive 722 and locomotives of the same series.*	
Grate area, in square metres	2·13		2·86	
	Locomotive 4742	*Locomotive of the same series*	*Locomotive 722.*	*Locomotive of the same series.*
Heating surface, in square metres . .	95·26	125 26	119·81	149·81
Superheater surface, in square metres .	30·00	. .	30·00	...
Working pressure, in kilog. per sq. cent.	10		8·25	
Diameter of cylinders, in millimetres .	500		500	
Stroke of pistons, in millimetres . . .	650		650	
Diameter of wheels, in metres	1·300		1·300	
	Locomotive 4742	*Locomotive of the same series.*	*Locomotive 722.*	*Locomotive of the same series.*
Weight empty, in kilograms	39,990	39,000	39,090	38,100

The dimensions of the cylinders and the working pressure have not been modified in the superheated-steam locomotives.

Readings have been taken of the temperature of the steam on the locomotive on the North Belgian system, when it was hauling 670 tons on the Tergnier-Charleroi line, where there are long up gradients of 5 per mil as a maximum. The following results were obtained : 15 to 25° C. (27 to 45° Fahr.) at starting, 104° C. (187° Fahr.) superheat on the average, 144° C. (259° Fahr.) of superheat as a maximum.

In the case of locomotive 4742, which has a working pressure of 10 kilograms per square centimetre (142·23 lb. per square inch), the amount of superheat while running is usually between 80 and 95° C. (between 144 and 162° Fahr.); on an up gradient it reaches 105 to 110° C. (189 to 198° Fahr.) the speed then being about 25 kilometres (15·5 miles) per hour.

As compared with similar locomotives using saturated steam, and doing the same work, the two superheated-steam locomotives have given results which appear satisfactory; it was found that they did the work more easily than the locomotives of the corresponding series without superheaters. But the duration of the experiment and the number of locomotives equipped with such apparatus are too limited to be able to deduce any figures as regards economy of coal or increase of power.

As regards the upkeep of the superheater, leaks have been found in the smoke tubes in the part going through the superheater and surrounded by the most superheated steam; moreover leaks occur where the tubes of that part are in the front tube-plate of the superheater.

The tightness of the Lentz valves has been checked and may be considered satisfactory.

Paris Lyons Mediterranean Railway.

One locomotive (No. 294) with Pielock superheater has been in use since September 1906.

One Notkin superheater, and thirty Schmidt superheaters, are at present being constructed.

Locomotive 294 with Pielock superheater. — The Pielock superheater consists essentially of a closed chest made of steel plate, about 1 metre (3 ft. 3 3/8 in.) long, placed in the barrel of the boiler, a little to the front of the dome; all the smoke tubes pass through it.

The latter, which alone support it, are expanded where they enter and where they leave the chest.

Two tubes of large diameter are fixed to the upper part of this chest; the one, H (fig. 16), which brings the steam, connects the superheater and the boiler; the other S ends at the regulator casing.

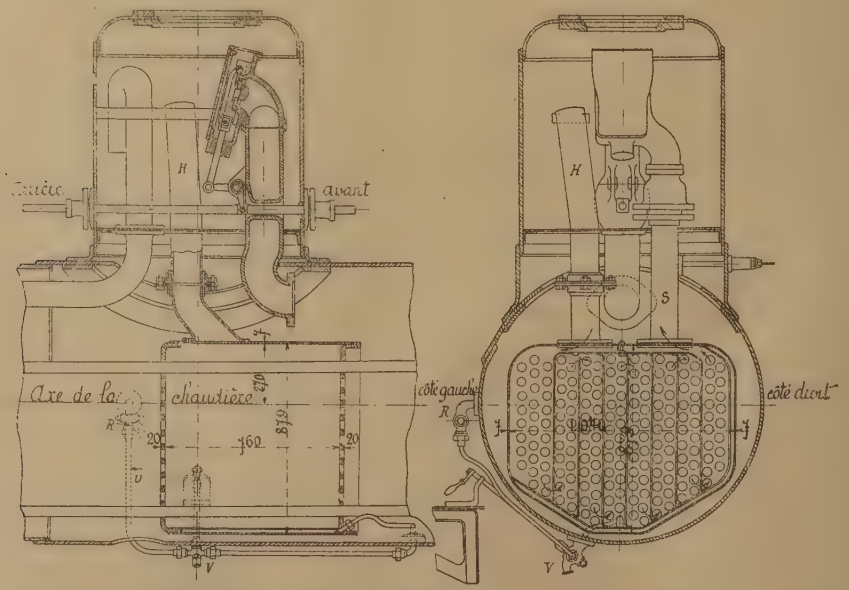

Fig. 16. — Paris-Lyons-Mediterranean Railway. — Pielock superheater.

Explanation of French terms : Côté gauche = Left side. — Côté droit = Right side. — Arrière = Back. Avant = Front. — Axe de la chaudière = Centre line of boiler.

The inside of the chest is divided into compartments by vertical partitions passing between the smoke tubes and pierced with holes, fixed alternately to the top and to the bottom.

The steam arriving through the pipe H is compelled to pass through each compartment in succession, flowing round all the smoke tubes, before reaching the pipe S and through this the regulator.

At the bottom part of the superheater there is a pipe connected, which leads to a three-way cock V, which is outside the boiler. This cock enables the superheater to be placed in communication either with the outer air, so as to empty it or run out condensed water, or with the boiler, so as to fill it by means of the pipe U and the cock R.

A mercury pyrometer is placed in the cab, which shows the temperature of the superheated steam when leaving the Pielock superheater.

As regards the different parts of the mechanism, the ordinary flat slide valves, the pistons, and the metal stuffing boxes of the piston and slide rods are the same as those which locomotive 294 had before the superheater was put in; a Detroit pressure lubricator has been added, and this is fed with special cylinder oil.

Locomotive with Notkin superheater. — The Notkin superheater is now being fitted to a compound locomotive of the series 4581-4640.

It superheats the steam before it enters the high-pressure cylinders.

In the smoke-box, before the tube-plate, there is a collector formed of a steel casting, resting on two supports fixed to the smoke-box ring (fig. 17).

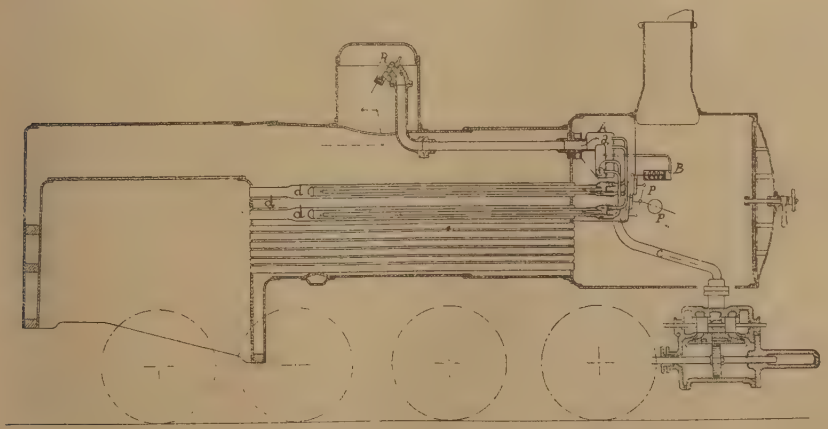

Fig. 17. — Paris-Lyons-Mediterranean Railway. — Notkin superheater.

The collector is divided into two separate compartments : the one, *a*, which

receives the saturated steam coming from the regulator; the other, *b*, which receives the superheated steam which then passes to the valve gear through the pipe C.

These two compartments do not communicate with each other except through the twenty-two tubular elements of the superheater.

Each element includes :

1° An outer ribbed tube 3,400 metres (11 ft. 1 $^{7}/_{8}$ in.) long. On the fire-box side, the tube is contracted and closed by a pressed cap riveted on; a second bronze cap, placed over this joint, protects it against the direct action of the hot gases and of the flames. On the smoke-box side, it is screwed into the back wall of the collector;

2° An inner smooth tube, placed inside the ribs of the former. This tube, which is open at both ends, has its front end expanded into the interior partition of the collector.

Each element is placed in a special smooth smoke tube, where it is kept central by four wings projecting from the bronze cap (with which they are cast in one piece) which protects its back end.

The boiler of locomotive 4638 does not differ from the other boilers of the same type except as regards the presence of these twenty-two special smoke tubes, arranged in the upper part of the nest of tubes in three horizontal rows (the first with seven, the second with eight and the third with seven tubes).

Finally a casing made of iron plate, fixed both to the smoke-box tube-plate and to the outside of the collector, forms a tight box, called the superheater box, which cuts off all the superheated elements from the smoke-box.

A door or damper P, placed at the upper part of the superheater box, permits or stops the flow of the hot gases from the fire-box past the superheater elements to the superheater box; the opening or closing of the regulator opens or closes the damper P automatically, by means of the device B.

This device, fixed outside on the left side of the smoke-box ring, consists of a small steam cylinder, communicating at its front end with the collector A; in it a piston can move whose rod by means of a lever opens or closes the damper P.

When the superheater is opened, the steam enters the collector, and then the cylinder B; the piston is pushed backwards and this opens the damper.

When the regulator is closed and there is no more steam in the collector, a return spring, assisted by the weight on the door forming a counterweight, pushes the piston forwards and the damper is closed.

When the regulator is opened, the damper P opens automatically, the hot gases from the fire-box pass round the superheater elements and raise them to a high temperature. At the same time the steam from the regulator enters compartment *a* of the collector, passes through the smooth inner tubes where it becomes dry and returns, becoming superheated, between the ribs of the outer tubes, to the compartment *b* from which it then goes to the piston valves.

Figs. 18 to 20. — Paris-Lyons-Mediterranean Railway.

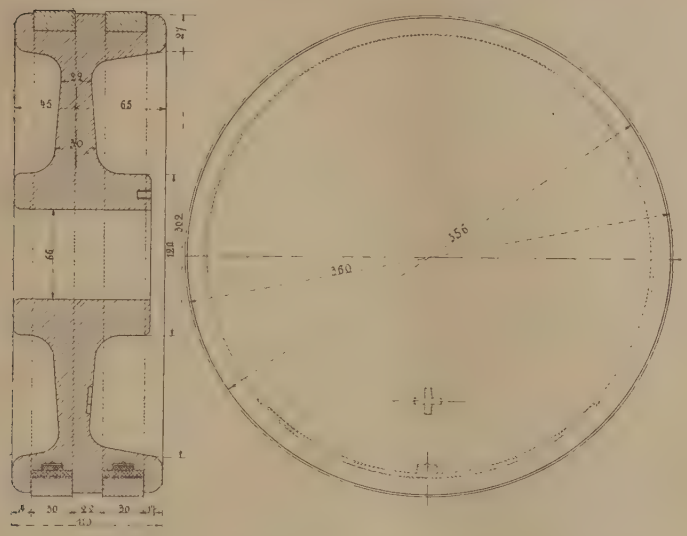

Fig. 18. — Piston with two rings with centring spring (Notkin superheater).

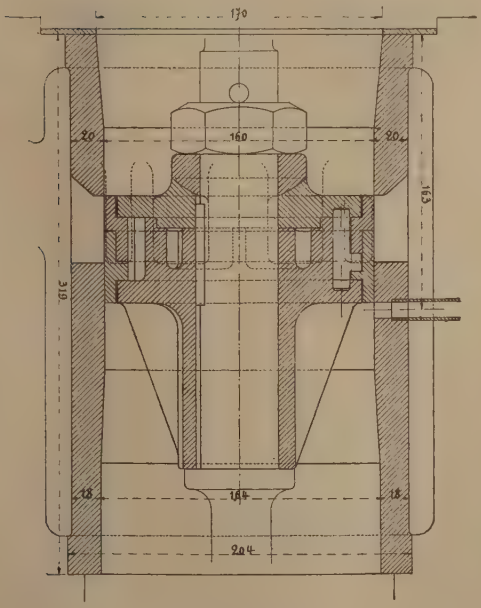

Fig. 19. — Bronze piston valve (Notkin superheater).

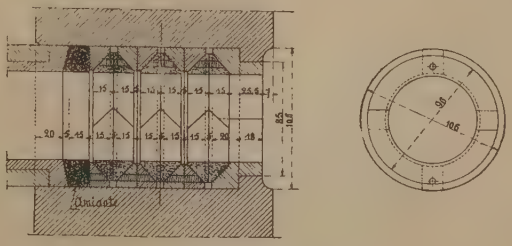

Fig. 20. — Metallic packing of the piston rod (Notkin superheater).

When the regulator is closed, the damper P closes automatically, the fire-box gases no longer pass round the superheater elements, and the steam contained in the latter escapes through the cylinders.

The working pistons and the slide valves present no special features; they are like those of the similar locomotives using saturated steam.

The pistons of the working cylinders have tail rods; they have two rings with centring springs (fig. 18).

The piston valves are of bronze, without cut rings, but with solid rings and centring spring (fig. 19); they are fixed on their rods so as to have diametral play, so that they can always be perfectly centred in the liner whatever the wear of the stuffing boxes may be.

The jackets of the steam chests are also made of bronze. The piston-rod packing (fig. 20) consists of twelve half-rings of white metal consisting of 65 per cent of lead, 20 per cent of tin and 15 per cent of antimony, placed between ten half-rings of bronze.

The packing is held between neck rings in two parts and the tightening device which bears on a lining equally in two parts. Between the lining and the metallic packing there is asbestos packing.

The tightening device has an oil hole ending in worsted kept against the piston rod by a worsted holder (fig. 21).

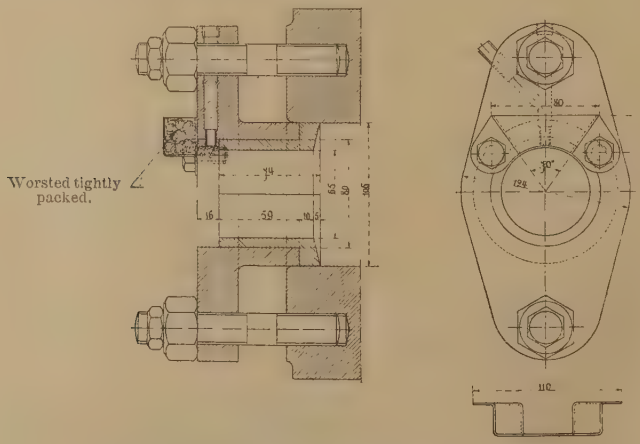

Fig. 21. — Paris-Lyons-Mediterranean Railway.
Tightening device for the piston-rod packing (Notkin superheater).

In front, the tail rod has no stuffing box; it encloses a casing similar to that used on the locomotives of the Belgian State Railway.

The front and back valve rod packing (fig. 22) consists of four rings of white-metal composed of 80 per cent of lead and 20 per cent of antimony, placed between three rings of bronze.

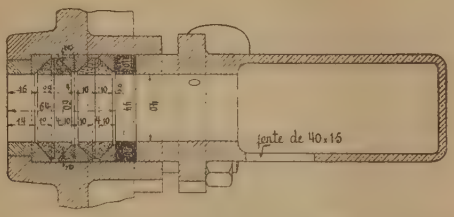

Fig. 22. — Paris-Lyons-Mediterranean Railway. — Metal packing of valve rods (Notkin superheater).

The packing is kept between the bronze neck ring and an asbestos packing on which the bronze tightening device bears. The tightening device in front has an oil hole ending in worsted kept against the rod by a worsted holder.

The front tightening device forms a casing for the valve rod, so that the front end of the valve rod is never in contact with the outer air. This tightening device also has an oil hole.

The pistons and valves are lubricated by means of a Detroit pressure lubricator, of the Galena pattern; the oil used is " Perfection valve oil XXX ".

As the special smoke tubes ending in the superheater box are inaccessible from that side, they can only be swept from the fire-box side by using the special device shown in figure 23.

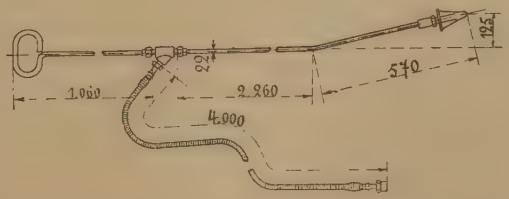

Fig. 23. — Paris-Lyons-Mediterranean Railway. — Jet for sweeping out the smoke tubes from the fire-box end.

Locomotives with Schmidt superheater. — Of the Schmidt superheaters which are being constructed, twenty will be fitted to four-cylinder compound locomotives; the high-pressure steam will be superheated.

The flat slide valves have been replaced by piston valves, with elastic and with non-elastic rings, with casings heated and not heated, so that the experiments may show which arrangement is the best.

The pistons have no special features; the cylinders are not fitted with pipes joining the two ends; they have atmospheric valves and at their ends they have safety valves 0·035 metre (1 3/8 inches) in diameter.

The back stuffing box of the piston rod contains three rings (fig. 24), each being in two parts and terminating at each end in a cone. The white metal used for these rings contains 80 per cent of lead and 20 per cent of antimony.

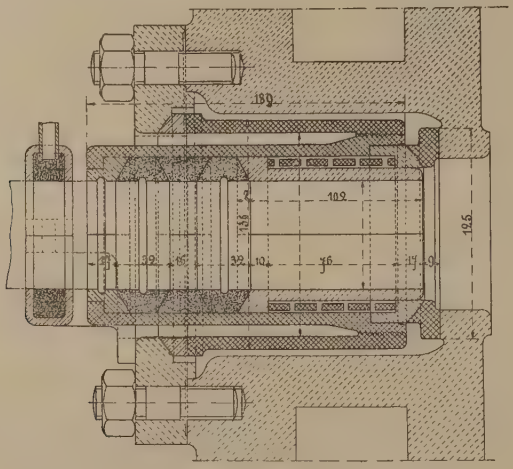

Fig. 24. — Paris-Lyons-Mediterranean Railway.
Piston-rod packing (Schmidt superheater).

The packing is held between the bronze neck ring, which is in two parts, and the cast-iron guide which is also in two parts.

This cast-iron guide does not bear directly on the bottom of the cylinder, but through a spring having a force of about 40 kilograms (88 lb.), on two rings with spherical seats, one made of cast iron, the other of steel; the latter bears on the bottom of the cylinder.

The tightening device proper is a steel casting and in two parts; the inner part bears on two rings of bronze and of cast iron. Bearing on the external part, there is a bronze ring with spherical seat on to which the back plate of the cylinder bears. An oiler in two parts, filled with worsted, completely surrounds the piston rod; an oil pipe terminates in this oiler.

The front metal packing is similar to that adopted in the case of the locomotive with the Notkin superheater.

The back stuffing box of the valve rod (fig. 25) consists of two coned rings of white metal; the latter contains 80 per cent of lead and 20 per cent of antimony.

The metal packing is held between the bronze ring, on which the cast-iron tight-

ening device bears, and the guide which is also of cast-iron. This guide does not bear directly on the cover of the steam chest; a spring having a force of about 30 kilograms (66 lb.) is interposed.

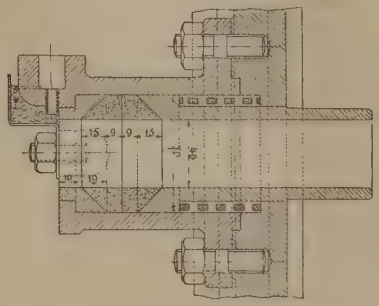

Fig. 25. — Paris-Lyons-Mediterranean Railway.
Valve-rod packing (Schmidt superheater).

The tightening device has an oil hole leading to worsted kept against the valve rod by a worsted holder.

The front stuffing box consists of a cast-iron guide placed on the front cover of the steam chest. This cover forms the " casing " for the valve rod and has an oil hole. The front end of the valve rod is hollow and pierced by a hole 8 millimetres ($^{5}/_{16}$ inch) in diameter, which places in communication the inside of the casing and the outlet of the steam chest.

One locomotive with Schmidt superheater will be fitted with Detroit pressure lubricators, of the Galena pattern; ten will have two Friedmann oil pumps.

The chief dimensions of the locomotives with superheater and of those of the same series but without superheater are given in the following table:

ITEM.	Locomotives 111-400		Locomotives 4581-4640			Locomotives 2661-2700	
	Without superheater.	With Pielock superheater.	Without superheater.	With Schmidt superheater.	With Notkin superheater.	Without superheater.	With Schmidt superheater.
Grate area, in square metres	2·32	2·32	2·30	2·30	2·30	2·98	2·98
Heating surface of fire-box, in square metres.	10·23	10·23	11·99	12·0243	12·0060	15·42	15·49
Heating surface of smoke tubes, in square metres.	132·29	111·62	217·43	153·2077	171·0531	205·75	137·45
Total heating surface, in square metres .	142·52	121·85	229·42	165·2320	183·0591	221·17	152·94

ITEM.	Locomotives 111-400		Locomotives 4581-4640			Locomotives 2661-2700	
	Without superheater.	With Pielock superheater.	Without superheater.	With Schmidt superheater.	With Notkin superheater.	Without superheater.	With Schmidt superheater.
Heating surface of square metres, of superheater	...	20·67	...	25·3966	15·3169 (1) 30·2001 (2)	...	30·02
Weight empty, in kilograms	47,380	...	50,120	...	...	...	...
Working pressure of boiler, in kilograms per square centimetre	11	11	15	15	15	16	16
Dimensions of working cylinders. Diameter, in millimetres	500	500	340	360	360	340	370
Dimensions of working cylinders. Length of stroke, in millimetres.	620	620	650	650	650	650	650
Dimensions of working cylinders. Volume displaced by the piston, in cubic decimetres	121·737	121·737	59·015	66·162	66·162	59·015	69·889
Increase in capacity of cylinders of locomotive with superheaters	...	0	...	12	12	...	18

(1) Without allowing for the ribs.
(2) Allowing for the ribs.

The locomotive 294, equipped with the Pielock superheater, being the only one with which experiments have as yet been made, the railways give the following observations about the results obtained when at work.

The temperature of the steam is 200° C. (392° Fahr.) at starting, and varies between 250 and 260° C. (between 482 and 500° Fahr.) after running 500 metres (547 yards); it does not exceed the latter figure.

During the trials the locomotive equipped with the Pielock superheater, as compared with a locomotive of the same series but without superheater, showed a saving of water of 12 to 15 per cent, and a saving of coal of 10 to 12 per cent.

The cost of lubrication of this locomotive is practically the same as that of a locomotive of the same type but without superheater.

No part of the superheater has given rise to any special difficulties.

Orleans Railway.

The Orleans Railway in 1906 equipped a certain number of single-expansion locomotives with superheaters in order to determine both the economic advantages which may result from this arrangement, as well as the difficulties of upkeep to which it gives rise. The system adopted was the Schmidt, with superheater tubes placed in the smoke tubes. The practical results obtained during this trials are related in the *Revue générale des chemins de fer*, December 1906; these together with those obtained by other railways, have led the Orleans Railway to decide to

apply superheaters of the same kind to thirty Decapod compounds and to sixty Pacific compounds, to be delivered in 1910.

The high-pressure valves of the Pacifics are piston valves; this device was already adopted in the first engines without superheaters in order ultimately to facilitate the application of superheating either to new units to be delivered, or to old ones already delivered, when the tube-plate was being replaced.

The Decapods, specially designed with a view to superheating, have both high-pressure and low-pressure valves and piston valves; it was subsequently found, from the results obtained in the different trials made on railways where compound locomotives using superheated steam are used, that piston valves could be dispensed with for the low pressure, and when adding the superheater to the *Pacific* locomotives, the flat slide valves were retained.

The following table contains the chief particulars of the Pacifics with and without superheater, and of the Decapods with superheater :

—	*Pacific* compound with four cylinders and without superheater.	*Pacific* compound with four cylinders and with superheater.	*Decapod* compound with four cylinders and with superheater.
Working pressure, in kilograms per square centimetre	16	16	16
Grate area, in square metres	4·27	4·27	3·80
Heating surface of firebox, in square metres.	15·37	15·37	15·10
Heating surface of tubes, in square metres.	241·88	195·70	186·00
Total heating surface, in square metres.	257·25	211·07	201·10
Surface of superheater, in square metres	...	62·60	52·10
Length of tubes between tube-plates, in metres	5,90	5·90	5·25
Diameter of tubes, in metres	Smooth. 0·050 × 0·055	Large, 0·125 × 0·133 Smooth. Small, 0·050 × 0·055	Large, 0·125 × 0·133 Smooth. Small, 0·045 × 0·050
Diameter of high-pressure cylinders, in metres.	0·39	0·42	0·46
Diameter of low-pressure cylinders, in metres.	0·64	0·64	0·66
Stroke of piston, in metres.	0·65	0·65	0·62 high-pressure 0·65 low-pressure
Diameter of driving wheels, in metres	1·85 1·95	1·85 1·95	1·40
Weight in working oder, in kilograms.	90,000 90,400	91,450 91,350	85,200
Adhesive weight, in kilograms	52,500	53,750	77,700
Weight of tender in working oder, in kilograms.	45,980	45,980	31,150

ITALY.

Italian State Railway.

The first locomotives with superheaters began work in November 1907. At present there are twenty-four, of series 640, with six coupled wheels and Krauss Bissel

truck, which are equipped with Schmidt superheaters; and in February 1908 there were twenty-four of the same series which were being built.

The superheater fitted to these locomotives is of the pattern with quadruple circulation of the steam.

The pistons, the stuffing boxes of the pistons and of valves are of the Schmidt pattern; the arrangement of the back stuffing box of the piston should be noted, in which the rings of white metal are outside the stuffing box proper so that the outer air may exercise a cooling action (fig. 26). The white metal used contains 14 per cent of tin, 10 per cent of antimony and 76 per cent of lead.

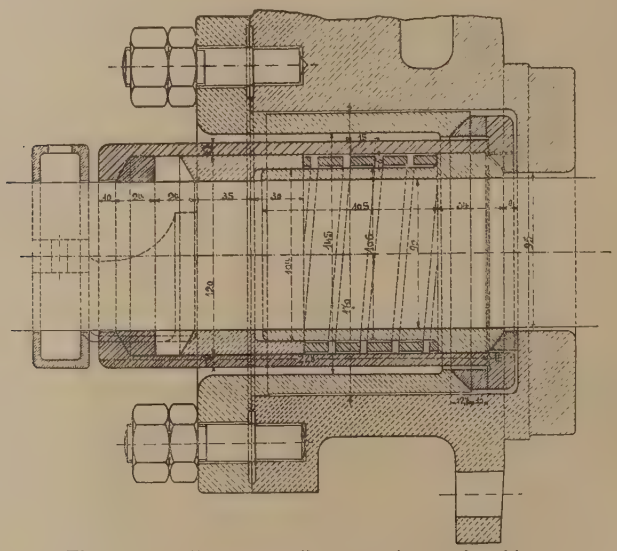

Fig. 26. — Italian State Railway. — Piston-rod packing.

The valves are piston valves, with spring ring and the casings not heated; they are grooved with Allan holes drilled in the rings.

The cylinders are fitted with atmospheric valves, with safety valves 0·05 metre ($1\ ^{31}/_{32}$ inches) in diameter, as well as with a pipe connecting front and back. The cock which closes this pipe is operated automatically, by means of a small steam piston which is in connexion with the main steam pipe. As soon as the regulator is closed, a counterweight returns the cock to the open position. This automatic device has not given rise to any trouble.

A Steinle and Hartung pyrometer indicates the temperature in the valve chest. The Fournier pyrometer is going to be tried.

The lubrication of the parts in contact with superheated steam is effected by

means of Michalk pumps. Wakefield oil from London, or "Vaporin" oil from Bremen, is used.

The superheater tubes are swept clean by means of compressed air jet; this is necessary at the end of each journey or each time the locomotive returns to the sheds; this system of cleaning gives every satisfaction.

The working pressure of the boiler of locomotives series 640 is 12 kilograms per square centimetre (170·67 lb. per square inch), while that of the two-cylinder compounds of series 630, using saturated steam, is 16 kilograms per square centimetre (227·57 lb. per square inch). It is above all with a view to a reduction in the cost of maintenance of these boilers that the Italian administration has adopted superheated steam and has formed series 640, similar to series 630, but with single expansion and a working pressure of 12 instead of 16 kilograms per square centimetre (170·67 instead of 227·57 lb. per square inch).

The following are the chief particulars of these two types :

—	Series 630, compound, with two cylinders.	Series 640, with superheated steam.
Type of locomotive	2-6-0	2-6-0
Diameter of cylinders, in millimetres	430 × 680	540
Stroke of pistons, in millimetres	700	700
Diameter of driving wheels, in metres	1·85	1·85
Working pressure of boiler, in kilograms per square centimetre	16	12
Grate area, in square metres	2·42	2·42
Heating surface, direct, in square metres	10·00	9·90
Heating surface, tubes, in square metres	114·8	98·8
Number of tubes of superheater	...	21
Diameter of large superheater tubes, in millimetres	...	133 × 125
Diameter of superheater tubes, in millimetres	...	28 × 36
Surface of superheater, in square metres	...	33·5
Weight empty, in kilograms	50,350	49,900
Weight in working order, in kilograms	55,000	54,500
Adhesive weight, in kilograms	44,000	44,000
Weight of tender, in working order, in kilograms	35,300	35,300

The locomotives of series 640, using superheated steam, as well as those of series 630 are used for passenger trains.

The amount of superheat and the time necessary for attaining the ordinary superheating are very variable according to the weight and speed of the trains and the number of stops during the journey.

The average superheating temperature, with an average load, amounts in the case of the express trains to 310 to 320° C. (590 to 608° Fahr.). The maximum which

has sometimes been attained is 350° C. (662° Fahr.). The ordinary working temperature always exceeds 300° C. (572° Fahr.).

Locomotives 640, as compared with locomotives 630, have given the following results :

A. — During the trials.

—	*Locomotives 630.*	*Locomotives 640.*
Weight hauled, in tons	192 to 305	218 to 319
Power developed in the cylinders, while running, in horse-power	700 to 800	800 to 1,000
Mean indicated horse-power, in cylinders	488 to 668	536 to 886
Useful power, measured at the tread of the wheels, in horse-power	446 to 630	517 to 773
Average ratio of power absorbed in the mechanism to total power, at speeds between 50 and 80 kilometres per hour	0·09	0·099
Consumption of steam per indicated horse-power-hour, in kilograms	9·7 to 13·8	8·1 to 13
Consumption of coal per indicated horse-power-hour, in kilograms	1·32 to 1·86	1·23 to 1·70
Consumption of coal per horse-power-hour measured at the drawbar of the tender, in kilograms	2·06 to 3·25	1·90 to 2·78
Consumption of coal per virtual hauled ton-kilometre, in kilograms	0·042 to 0·062	0·035 to 0·047

B. — In the ordinary service, during a period of three months (April to June 1908).

Series of locomotives.	Numbers of locomotives.	Distance run.	Average weight hauled (carriages), in tons.	Consumption of coal, in kilograms.		
				Total.	Per kilometre.	Per virtual hauled ton-kilometre (carriages).
630	6341	17,393	190	191,100	10·98	0·0465
	6349	18,024	186	190,005	11·04	0·0484
640	64005	18,746	190	198,195	10·57	0·0452
	64006	17,761	194	190,015	10·76	0·0453
	64007	18,058	187	197,795	10·95	0·0474

In practice, locomotives 640 haul 10 per cent greater loads than the similar compounds with two cylinders (group 630).

The total lubricant consumed by locomotives 640 is about 15 per cent greater than that consumed by compound locomotives 630, doing the same amount of work.

During the trials with locomotives 640, it was found preferable, when the locomotive was not working at full power, to reduce the opening of the regulator rather than to change the cut-off.

The administration of the Italian State Railway has not yet any statistical date as to the special cost of upkeep of superheated-steam locomotives; the twenty-four superheated-steam locomotives which have been in use for one year have given rise to no special difficulties in upkeep as compared with similar compound locomotives using saturated steam; with good lubrication and careful adjustment of the packing, the tightness of the latter is satisfactory.

Milan Northern Railway.

This railway has twenty-four superheated-steam locomotives in use; four of these have been in use for two years and nine for one year; six are at present being built.

The superheater is of the Schmidt pattern, with quadruple circulation of the steam.

The steel pistons and the piston-rod and valve-rod stuffing boxes are also of the Schmidt pattern and have no special feature.

The valves are piston valves, 0·25 metre ($9\ ^{27}/_{32}$ inches) in diameter, with one single cut ring. The jacket has triangular openings for admitting the steam, the larger ones being towards the bottom. The oblique bars distribute the wear on the ring over its whole circumference. At the outlet side, the openings are rectangular, the large section towards the top of the discharging side. This is the same arrangement which has for a long time been adopted on the Belgian State Railway. In addition to safety valves 0·06 metre ($2\ ^{3}/_{8}$ inches) in diameter, on the bottom of the cylinders, they also have a pipe connecting part of front and back, which is indispensable when making long runs with regulator closed.

The equipment is completed by a compensation pyrometer fixed to the collector and by a Friedmann oil pump supplying the oil known as « Perfection valve oil » supplied by the Vacuum Oil Company.

The superheated-steam locomotives have, as compared with similar saturated-steam locomotives, the diameter of the cylinders increased 10 per cent. The working pressure of the boiler has not been altered. The ratio of general heating surface to superheater surface is 3·5, and the locomotives weigh about 1 ton more.

The results obtained on the Milan Northern Railway are of interest.

The maximum superheating temperature is 350 to 360° C. (662 to 680° Fahr.), the steam being between 180 and 190° C. (between 356 and 374° Fahr.); this is attained after a kilometre or two, the sooner the heavier the trains, the higher the speed and the lower the water-level; in connection with these figures it has to be remembered that the superheaters of the locomotives of this railway have a large surface, equal to 30 per cent of the heating surface.

The tractive effort of some of the single-expansion locomotives using superheated

steam has been increased 25 per cent, for an increase in the coal consumption of 10 per cent; the water consumption has remained practically the same.

The modified locomotives do the same work as the saturated-steam locomotives, which burn on the average 15 per cent more coal and consume at least 25 per cent more water.

The cost of lubrication has not been appreciably increased by the superheat.

As regards upkeep, the administration states that leakages in the valve gear have never been entirely eliminated, but they are nearly insignificant; perhaps the one cut ring has not all the elasticity required.

Water-tube boilers.

The application of water-tube boilers to locomotives is still in the experimental stage.

Among the patterns under trial, attention is drawn to the boiler with water-tube fire-box designed by Mr. Brotan, the chief engineer of the Austrian State Railway. It was specially designed with a view to the burning of lignite, containing much sulphur, which quickly attacked the copper stays and plates of the usual locomotive boilers. On the other hand, the ultimate tensile strength of copper, which is 22 kilograms per square millimetre (312·90 lb. per square inch) in the cold is only 18·5 kilograms per square millimetre at 197° C. (263·12 lb. per square inch at 387° Fahr.), the temperature corresponding to a pressure of 15 kilograms per square centimetre (213·34 lb. per square inch); and this reduction in the strength is still greater when the fire-box plates in contact with the water are covered with hard scale which causes the heat to be transmitted more slowly and may result in overheating the copper of the fire-box; under these conditions the tube-plates become much weaker; they swell out between the heads of the stays; the thread of the latter is then no longer in proper contact and leaks occur. All these disadvantages, which become aggravated when high pressures are used, led Mr. Brotan to design a locomotive boiler in which the copper plates and stays are replaced by water tubes made of steel; Mr. Brotan has made all the different parts very accessible, while the fire-box is at the same time easy to clean; it has also to be noted that the very active circulation of the water in the tubes tends to prevent the formation of scale.

The Brotan boiler is well known; a complete and detailed description of the most recent pattern is given in the *Portefeuille économique des machines* of January 1908.

The Belgian State Railway and the French Midi Railway has two Brotan boilers in use, and the Paris-Lyons-Mediterranean Railway is also going to try two of them.

The French Midi Railway writes: "Since we increased the boiler pressure to 15 and 16 kilograms per square centimetre (213·34 and 227·57 lb. per square inch),

the upkeep of the ordinary fire-boxes and stays has become very troublesome. We frequently have to replace broken stays and to repair the tube-plates which crack at their upper corners. With the Brotan boiler, where the fire-box is formed by water tubes close together, these inconveniences disappear, and it appeared to us of interest to make a trial of these boilers, in order to ascertain whether they gave better results from the point of view of maintenance than our present boilers."

To the engineers of the Paris-Lyons-Mediterranean Railway, the Brotan boiler appears to have recommended itself by certain advantages such as : better utilization of the hot gases; better circulation of the water; fire-box less liable to damage than the ordinary fire-box; ease of increasing the working pressure of the boiler.

The two Brotan boilers which the French Midi Railway has are on two-cylinder compounds of the type 2-6-0. The administration is not yet able to give any opinion as to how they behave, as these two boilers have been in use too short a time.

The two Brotan boilers of the Belgian State Railway are on two goods locomotives with six coupled wheels, with their total weight adhesive weight; they started working October last. The working pressure is 10·5 kilograms per square centimetre (149·34 lb. per square inch). So far they have remained very tight; the steam production is good. The period of trial is as yet too short to make it possible to give any opinion as to the advantages or disadvantages of these boilers as compared with the ordinary boilers.

The Paris-Lyons-Mediterranean Railway has recently started on its system, where the feed water is of very bad quality, locomotives equipped with a water-tube boiler on a system devised by Mr. Robert, the chief locomotive engineer of the Algerian lines. Mr. Herdner, the chief engineer of the Midi Railway, in his memoir on the locomotives at the Liége exhibition, states : " Although resembling the Brotan boiler as far as the arrangement of the fire-box is concerned, the Robert boiler differs completely in the other parts, as the smoke tubes are done away with entirely, and they are replaced by water tubes. Nevertheless, and although the two boilers were worked out independently, the Robert boiler may be derived from the Brotan boiler : 1° by increasing the diameter of the upper collector; 2° by contracting on the other hand the barrel and lowering it at the same time, after previous removal of the smoke tubes, which leads to the lengthening of the connecting pipes; 3° by connecting the upper collector with the barrel, reduced to acting as a lower collector, by a large number of water tubes bent in varying ways, but all presenting their concave side towaads the central plane. The tubes furthest from that plane are the connecting tubes which prolong towards the front, both on the right and on the left, the tubular side walls of the fire-box. They thus form a sort of casing which the hot gases flow over before reaching the smoke-box and in the middle of which the other water tubes are arranged in staggered rows."

This boiler has been described in the *Revue générale des chemins de fer*, April 1905.

Although the administration shows that the trials are of too recent a date to make

it possible to draw conclusions, it is to be assumed that it is satisfied with the first results as it is also going to try a boiler of this kind on its metropolitan lines.

The French Northern Railway, as an experiment, has had built by Messrs. Schneider & Co., of Creusot, a locomotive with a water-tube fire-box and a barrel with smoke tubes. This is an express locomotive with four coupled wheels between two bogies. This first application is still too recent to enable the administration to give any opinion as to any advantages obtained and to make any valid comparison between water-tube fire-boxes and fire-boxes with walls of water.

The Italian State Railway during 1908 started working eight motor luggage-vans with water tubes on the Komarek system. Up till now they have not given any particular trouble; the administration cannot as yet give any other information on the subject.

Feed-water heaters.

Two French railways, the Northern and the Paris-Lyons-Mediterranean, are trying the Caille-Potonié feed-water heater. On the Italian State Railway, the question of heating the feed water is at present being investigated.

The principle of the Caille apparatus consists in utilizing the heat of part of the exhaust steam passing through the superheater, in order to heat the water coming from the tender to about 95° C. (203° Fahr.), during its passage through the apparatus.

The water is then sent into the boiler, as and when required, by a special hot-water pump.

The heater which is being tried on the Paris-Lyons-Mediterranean includes :

1° A pipe for taking exhaust steam (fig. 27).

A special exhaust column, with an ejector *a*, is fixed on the exhaust piping from each cylinder.

A little below this ejector a pipe *b* branches off, to take exhaust steam and lead it to the feed-water heater at its other end.

The entrance to this branch can be closed or opened to a graduated extent by a flap-valve *p* operated from the drivers's cab (1); this enables the driver to control the amount of steam entering the heater.

The steam not drawn off through the branch escapes by the conical orifice *c* and draws out through the pipe *d* the remaining steam coming out of the heater. Owing to this ejector, the current of steam retains its velocity up to the blast pipe;

(1) The flap-valves of the two exhaust columns are connected by rods and levers and are operated simultaneously by a rod turned by a hand-wheel placed below the reversing gear.

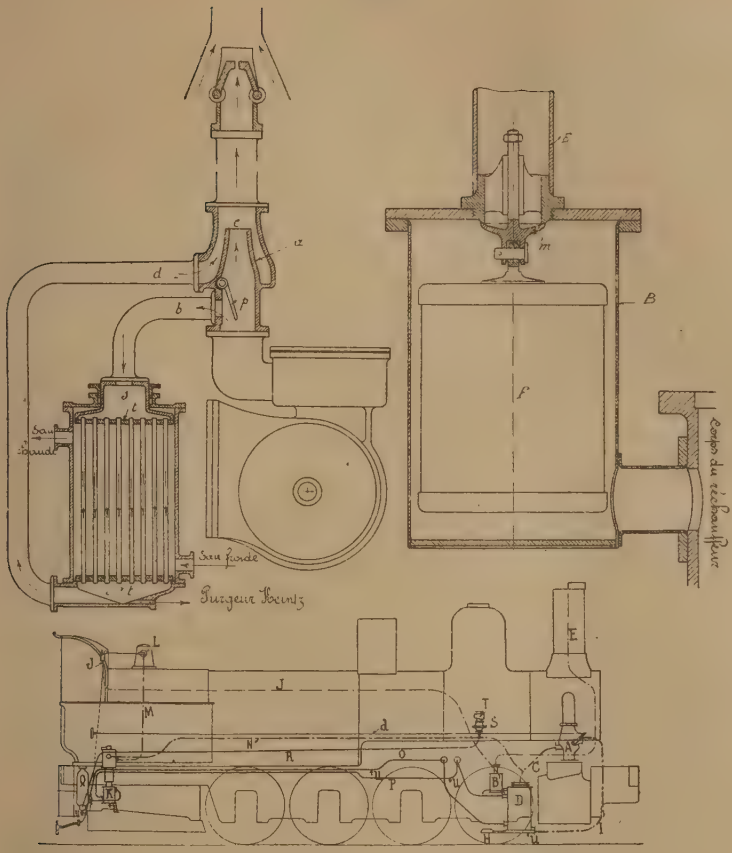

Fig. 27. — Paris-Lyons-Mediterranean Railway. — Feed-water heater, on the Caille-Potonié system.

REFERENCE:

A = Special exhaust steam column.
d = Rod for operating the flap valves for taking exhaust steam.
C = Pipe for taking exhaust steam.
D = Body of heater.
B = Valve box for blowing off steam formed in the heater.
E = Blow-off tube.
H = Heintz drain cock.
J = Return pipe for exhaust steam.
J = { Pyrometer. Flexible tube of pyrometer.
K = Hot-water pump.
L = Steam supply to pump.
M = Steam pipe to pump.
N = Pump exhaust going to heater.
O = Pipe through which the cold water enters the heater.
P = Hot-water return pipe to pump.
Q = Hot-water vessel.
R = Pipe delivering water to boiler.
S = Special valve box.
uu = Drain cocks.

Explanation of French terms : Eau chaude = Hot-water. — Eau froide = Cold-water. Purgeur Heintz = Heintz drain cock. — Corps du réchauffeur = Body of heater.

in this way the harm which this removal of steam might cause to the forced draught in the fire-box is reduced.

2° The heater proper.

The heater which is placed below the boiler is fixed to the frame plates and to the smoke-box.

It consists of two vertical symmetrical cylinders, cast in one piece.

Each of them encloses a series of vertical tubes, fixed to two tube-plates *t* and *t'* and receives the exhaust steam of the steam cylinder at its side.

The latter, arriving in the upper chamber S, passes through all the tubes and enters the lower chamber *i*, which is fitted with a Heintz draining device for removing the condensed water; from these it is passed through the pipe *a* to the exhaust column.

The water coming from the tender arrives in the heater above the lower tube-plate, circulates around the tubes in an opposite direction to that of the current of steam and becomes heated; finally it passes out through a pipe fixed near the top of the tubes in order to go to the special hot-water pump.

A pyrometer placed in the cab enables the driver to see what the temperature of the water in the heater is.

Finally the hot-water chambers of the latter each have fixed to their upper part a box B.

As long as the temperature of the heated water does not attain 100° C. (212° Fahr.), this box remains full of water and the valve *m* is kept against its seat by the float *f*.

But if the temperature reaches 100° C. (212° Fahr.), the steam which forms rises to the top of the box and drives back the hot water; the float consequently descends, and with it the valve *m*; the steam escapes into the blow-off tube E which goes up to the top of the chimney of the locomotive.

A valve placed at the upper part of this tube and kept on its seat by its weight alone, prevents, in case of any defective closing of the valves *m*, any entrance of air into the heater while the pump is at work; the latter works the better the less gas is carried along by the hot water pumped.

This arrangement also allows the air contained in the empty heater to escape when water is put into the latter.

3° A special hot-water pump.

This double-action pump is fixed vertically at the back of the right-hand frame plate.

It has a steam cylinder to drive it, similar to that for the air pumps of the locomotives, and below this there is a special pump barrel for the hot water.

The water pumped passes into a vessel with its upper part filled with air, to take up shocks. It then passes through a delivery pipe to two valve boxes on the right-hand side of the boiler.

The lower box is a special box with three flap valves in one plane; the upper box is the regulation Paris-Lyons-Mediterranean box with stop-cock.

A spring is placed between the flap and the top of the box to absorb any water-hammer action.

A pressure gauge fixed to a branch from the vessel and placed in the cab shows the pressure in the vessel.

Next to this pressure gauge, there is placed the hand-wheel operating the valve supplying steam to the pump engine.

At the lower part of each cylinder to the back, there is screwed in a washing-out plug. When this is taken out, a jet of water can be sent against the corresponding nest of tubes so as to remove the scale which does not adhere firmly to it.

A drain cock, operated by a handle placed outside the frame, makes it possible to draw off any mud or pieces of scale which have accumulated in the bottom of the water compartments.

This is done when the boiler is washed out.

The instructions issued by the administrations for the use of the feed-water heater are given in an appendix.

The Paris-Lyons-Mediterranean Railway has fitted the Caille superheater to a locomotive with eight coupled wheels and outside cylinders. The trials are at present being made.

The French Northern Railway first fitted one to a goods locomotive with eight coupled wheels and outside cylinders, and then one to a suburban locomotive with four coupled wheels and two bogies.

In the case of the locomotive with eight coupled wheels, the hot water was pumped and delivered by means of two different horizontal pumps controlled by one of the mechanisms of engine.

As this arrangement did not prove satisfactory, the pumps were replaced in the second locomotive by a little steam pump similar to that used for the Westinghouse compressor.

The results obtained with these two locomotives have up to the present been quite satisfactory.

The apparatus works properly.

The pump supplies enough water for consumption in all cases; the average temperature of the heated water before it enters the boiler varies between 85 and 90° C. (between 185 and 194° Fahr.)

The adoption of this system simplifies the work of the fireman who, once the pump is adjusted to supply the quantity required, has no longer anything to do with it, particularly in the case of through trains.

From the point of view of economy, the consumption of water is the same as in the case of a locomotive of the same series fed by an injector; and the saving of fuel has been 0·750 kilogram (2·661 lb. per mile) as compared with similar locomotives fed by an injector.

*

As regards cost of upkeep, that of the Caille apparatus does not exceed that of the injector.

It has been observed that the vacuum in the smoke-box is not appreciably affected by the branching-off of the exhaust steam.

The railway is going to extend the application of the Caille heater to five suburban locomotives with six coupled wheels and two bogies, which are at present being designed.

* * *

On the Orleans Railway, Lenchauchez feed-water heaters have been fitted to several series of goods locomotives between the years 1881 to 1890. About thirty of them still have such feeders.

The cold water coming from the tender is delivered by a first pump driver by an eccentric fixed to a driving axle into the heater, where it meets a current of steam coming from the exhaust, which has previously passed through an oil separator.

The water, heated to a temperature of nearly 100° C. (212° Fahr.), then goes to a second pump which delivers it into the boiler.

The two pumps are operated by eccentrics fixed to the driving axle opposite each other.

Drawings of the details and of the whole arrangement of this apparatus on locomotives of the Orleans Railway were published in the *Bulletin de la Société des ingénieurs civils de France*, for June 1890.

CONCLUSIONS.

1° The majority of the railway administrations have tried or are trying superheated steam on locomotives;

2° Those of them who have already used superheat for sometime, have extended its application, in some cases even to a considerable extent; none of them have given up its use;

3° The economies of fuel and of water are in direct ratio with the amount of superheat. They are greatest when the locomotive does considerable, and above all, continuous work. In the case of single-expansion locomotives, they have reached 29·64 per cent of coal and 28·67 per cent of water in certain trials made on the Belgian State Railway.

On the other hand, any appreciable saving only begins to appear when the superheat is at least 30 or 40° C. (54 or 72° Fahr.).

4° The results obtained in current practice, like those obtained in the trials, are clearly in favour of superheating; single-expansion superheated-steam locomotives show an economy of coal of up to 18·20 and even 22 per cent as compared with

similar saturated-steam locomotives which have done the same work, that is to say which have hauled the same trains under conditions which were absolutely identical;

5° The temperature of the superheated steam must not exceed 350° C. (662° Fahr.). A temperature of 320° C. (608° Fahr.) seems, in the case of single-expansion locomotives, to give the best results from the point of view of efficiency and the proper preservation of the different parts;

6° In consequence of the greater fluidity of superheated steam, the losses due to wire-drawing are reduced, and the pressure at admission is higher than with saturated steam; this enables the locomotives to attain higher speeds;

7° Level lines on which the locomotives run long distances at a uniform rate, and also long and steep up gradients are particularly favourable to locomotives using superheated steam;

8° Superheating gives less advantageous results on " sawteeth " lines, formed by a succession of up and down gradients of short length; the same applies, for similar reasons, to trains with frequent stops, particularly if the stops are long;

9° As superheating can in certain cases increase the power of a single-expansion locomotive 30 per cent it follows that two-cylinder locomotives, of simple and economic construction and reliable, can be retained as type without any need for going in for very complicated locomotives;

10° By equipping a compound locomotive with a superheater, its efficiency is increased. The four-cylindrer express compounds of the former French Western Railway are from 13 to 14 per cent more economical than similar compounds using saturated steam;

11° Moreover superheating makes it possible, in the case of compounds, to effect economies of coal which were found to be 12·3 per cent in the trials made with express locomotives on the Belgian State Railway, and 7·3 to 10 per cent in the trials made on the Italian State Railway, also with express locomotives; both figures being per indicated horse-power;

12° It would appear from the comparison of the figures given above obtained with locomotives in good condition that the four-cylinder express compound locomotive using superheated steam does not show any marked advantage over the similar four-cylinder single-expansion locomotive using superheated steam; the latter moreover has the advantages of simple construction, easy driving and stability at high speeds.

The advantage in favour of the compound locomotive using superheated steam may become more marked when valve gear is used which is liable to develop important leaks quickly;

13° The economy of water makes it possible to feed the boiler at longer intervals, a marked advantage on up gradients, to increase the distance run with the same amount of stores, and to wash out the boilers at longer intervals;

14° The extra power obtained by superheating is not at once available : it is only

obtained after running a certain distance, varying with the weight and with the speed of the train, and with the profile of the line;

15° As superheating is more economical the lower the initial pressure of the steam, it is not as a rule advisable to have a high pressure in the boiler. At the same time the great cost of upkeep of boilers working at high pressures is avoided;

16° A high superheat makes special arrangements of the packing, the pistons and the valve gear necessary, as well as the use of a number of lubricators using special oil.

However, as far as compound locomotives are concerned, the results obtained in the different trials made on the French railways have shown that the different parts of the low-pressure gear can be identical with those of similar locomotives not equipped with superheater;

17° The addition of a Schmidt superheater to a single-expansion locomotive of the Belgian State Railway, and the necessary modifications of the parts in contact with the superheated steam, result in increasing the price of the locomotive by about 4,000 to 5,000 francs (£160 or £200), royalties not included, and the locomotive is about 2 tons heavier;

18° In order to be kept tight, the stuffing boxes, the valves and the pistons require, owing to the great fluidity of the superheated steam, more careful maintenance than when saturated steam is used.

As regards more particularly the stuffing boxes, the results obtained on the Italian State Railway show that, subject to good lubrication and very careful adjustment, their tightness is satisfactory (in the case of the Italian State stuffing boxes, the white-metal rings are quite outside and cooled by the outer air);

19° It is indispensable to use oil of special quality when using superheated steam. The Belgian experiments show that only trouble is to be expected with cheap oils; their use not only does not offer any advantage, but results in quick wear of the rings and in leaks in the packing; the pistons are liable to jam and seize in the cylinders, the rings become clogged, etc.;

20° The application of water-tube boilers and of feed-water heaters to locomotives is still in the experimental stage.

May 1909.

SUPPLEMENTARY NOTE

After this report had been sent in, there appeared, in the *Revue générale des chemins de fer*, July 1909, a note by Mr. Bachellery, the engineer of the Midi Railway, on the comparative trials made with locomotives 5005 and 4008 of that company. The results obtained agree with those obtained on the Belgian State Railway with two express locomotives which were as similar as possible, the one with four cylinders, simple expansion and superheater, the other with four cylinders, compound and using saturated steam.

Locomotive 5005 has two cylinders, and ten coupled wheels; the whole weight is adhesive weight and superheated steam is used.

Locomotive 4008 is a compound with four cylinders, eight coupled wheels and a Bissel truck.

The following are the chief particulars of these two locomotives :

—	*Locomotive 5005.*	*Locomotive 4008.*
Working pressure, in kilograms per square centimetre. . .	12	15
Heating surface, in square metres.	141·80	253·26 (Tubes Serve)
Heating surface, in square metres	44·20	...
Superheating surface, in square metres	2·70	2·80
Grate area, in square metres	1·35	1·40
Diameter of driving wheels, in metres	0·63	0·39 × 0 60
Stroke of pistons, in metres	0·66	0·65
Adhesive weight, in kilograms.	86,000	65,700
Total weight in working order, in kilograms	86,000	72,800

The trials were made on the line from Béziers to Neussargues, between Aguessac and Engayresque; this section is 15 kilometres (9·32 miles) in length and has a nearly continuous up gradient of 33 per mil.

A trial train was specially made up, consisting of three high-sided wagons filled with coal and a loaded van, so that the weight was 190 tons, the normal load of locomotive 4008.

This train was hauled during six days by locomotive 5005 and by locomotive 4008; each locomotive made a journey each day, alternately in the morning and the afternoon.

The coal consumption was noted for each journey, not including the fuel required for lighting up; and the water consumption, allowing for the loss when starting the injectors.

The results of these six days of trial were as follows :

—	*Locomotive 5005.*	*Locomotive 4008.*
Consumption of coal, from Aguessac to Engayresque, in kilograms	690	750
Consumption of coal per kilometre, in kilograms	45·4	49·3
Consumption of water, from Aguessac to Engayresque, in litres.	5,650	6,700
Consumption of water per kilometre, in litres	371	447
Mean cut-off while running, per cent.	40	H. P. 70 B. P. 60
Mean velocity, in kilometres per hour.	15 to 16	15 to 16
Water evaporated per unit of coal.	81·1	81·9

Thus, hauling the same train, locomotive 5005 consumed 8 per cent less coal and 15·7 per cent less water than locomotive 4008.

Conclusion 12 given above accordingly seems equally applicable to goods locomotives.

* * *

Trials have recently been made on the Belgian State Railway in order to examine the variations in the tractive effort of a superheated-steam locomotive at different speeds, for a given cut-off. The trials were made with an express locomotive with four equal cylinders, similar to that described supra. The results are shown in

figure 28 and in the table given below; the train hauled weighed 332 tons, the cut-off was set at 26 per cent and the regulator was half open.

Mean speed over 500 metres, in kilometres per hour.	Mean tractive effort, in kilograms.	Pressure in kilograms per square centimetre.	Temperature of superheated steam, in degrees centigrade.	Mean speed over 500 metres, in kilometres per hour.	Mean tractive effort, in kilograms.	Pressure in kilograms per square centimetre.	Temperature of superheated steam, in degrees centigrade.
19	5,750	13	265°	108	3,975	13	287°
50	5,150	...	...	108	3,975	...	...
62	4,850	...	266°	108	3,950	13 1/4	289°
68	4,700	...	...	108	3,950	...	...
74	4,550	...	268°	110	3,925	13 1/4	290°
78	4,450	...	...	112	3,925	...	...
83	4,350	...	269°	113	3,900	13 1/2	292°
87	4,300	...	...	112	3,900	...	...
88	4,250	...	270°	112	3,875	13 1/2	294°
90	4,250	...	...	114	3,875	...	...
91	4,200	...	272°	114	3,875	13 1/2	297°
93	4,150	...	...	115	3,850	. .	...
94	4,150	...	273°	115	3,850	13 1/2	300°
95	4,120	...	...	116	3,850	...	...
98	4,100	...	278°	117	3,850	13 1/2	302°
102	4,050	...	...	118	3,850	...	...
103	4,025	...	281°	120	3,825	13 1/2	304°
103	4,025	...	...	120	3,825	...	...
106	4,000	...	284°	121	3,825	13 1/2	305°
107	4,000	...	...	123	3,825	...	...

These different values of the tractive effort show the happy influence of the fluidity of the superheated steam, from the point of view of power; from 103 to 123 kilometres (64 to 76·5 miles) per hour, the variation is only 200 kilograms (440 lb.), or 5 per cent; at 123 kilometres (76·5 miles) per hour a tractive effort of 3,825 kilograms (8,433 lb.) is still developed, and the power obtained amounts to 1,750 horse-power.

The diagram was obtained from the records of Mr. J. Doyen's inertia ergometer, which was described in the *Bulletin of the Railway Congress*, No. 3, March 1909, page 169.

The total effort is equal at any given moment to the sum of the resistances to rolling and of the forces required to overcome gravity and produce the acceleration.

The law of the rolling resistances of the train which is subjected to trial is very easily established from the records obtained with the ergometer when running with regulator closed.

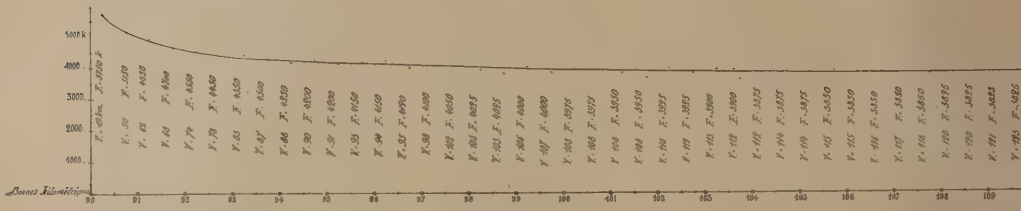

Fig. 28. — Express locomotive with four equal cylinders using superheated steam. — Trial made on the Brussels-Osten line between kilometres 90 and 110.

Explanation of French terms : Bornes kilométriques = Kilometre posts.

The forces necessary to overcome gravity and produce acceleration can be deduced from the diagram obtained by means of the ergometer when running with regulator open.

It is hence possible to determine, in a simple and accurate way, the total effort at any given moment.

APPENDIX

BELGIUM.

Belgian State Railway.

Instructions for driving superheated-steam locomotives.

Before leaving the shed, the driver must specially check the proper working of the automatic gear operating the damper and that of the mechanical lubricator oiling the pistons and valves which can only be fed with the special oil for superheated-steam locomotives. He checks that the springs of the safety valves of the cylinders are perfectly clean.

As the superheated-steam locomotive has piston valves, which cannot be raised, it is important to prevent any water from being carried over into the cylinders.

Several precautions have to be observed for this purpose, both when starting and while running.

At each start the regulator must be opened slowly.

When leaving the depot, when the cylinders are not yet heated, it is advisable to have the drain cocks open during the first few revolutions of the wheels.

While running, the driver must avoid any excess of water in the boiler. The regulator is opened to such an extent that the pressure of the steam in the valve chests is always a little lower than that in the boiler.

If in spite of these precautions, any water is carried over while running, the driver will be informed of the fact by a sudden drop in the temperature of the superheated steam indicated by the pyrometer. In this case the drain cocks must be opened and the opening of the regulator reduced so as to dry the steam by throttling.

The temperature of the superheated steam must not exceed 350° C. (662° Fahr.). If this is exceeded, the driver will reduce for the period required the opening of the damper of the smoke chamber by shortening the stroke of the piston of the small engine of the automatic gear.

The cut-off in the cylinders must never be too reduced. If the locomotive has only to develop a small amount of power, the driver uses the regulator to reduce the pressure of the steam in the cylinders.

Excessive lubrication of the pistons and valves is to be avoided. Any such excessive lubrication is shown by the formation of a ring of coom on the edge of the discharge pipe.

In case of any damage to one of the superheater tubes, the driver at once closes the regulator and takes the steps necessary for calling for help.

As regards maintenance, the large smoke tubes and the tubes of the superheater are to be kept clean, and are cleaned like the ordinary smoke tubes.

Instructions for the operation and maintenance of the pistons and valves of superheated steam locomotives.

A. — *Pistons.*

With superheated steam, the piston must never bear on the cylinder; it must "float" and be supported on the one side by the cross-head shoes and on the other by the tail rod.

The back piston-rod packing is exclusively for tightness and must not support the piston rod. If this were otherwise, the rod would in fact be guided at three points; and this is very difficult

to realize and maintain. It is moreover for this reason that the back packing is so constructed that it can give to a small extent.

The principles of this operation must be rigidly adhered to in current service, and with this object in view, the play at the shoes of the cross-heads and at the rings of the guides of the tail rods will be taken up in the proper time.

It is in order to provide for any risk of seizing in the cylinder which might arise from any eventual negligence in this maintenance, that it is prescribed to place a piece of packing 2 millimetres ($^{5}/_{32}$ inch) thick between the rings and the bottom of the grooves, at the lower part of the body of the piston which is a steel casting.

The play of the piston in the cylinder must be 3 millimetres ($^{1}/_{8}$ inch) and it is equally to avoid with still greater certainty any risk of seizing in the cylinders that the outer corners of the body of the piston, of the grooves and of the rings must be slightly rounded. If after a certain period of service these corners have again become sharp, they should again be rounded,

At the periodical examinations of the pistons, the rings are examined to see if they have not become fixed, that is to say whether they are still free to displace themselves vertically in the grooves. Caré is taken that the grooves in the corresponding circumference of the rings and the holes in them are not choked by coom.

When the piston is put in place, care is taken to provide for the play of 1 millimetre ($^{3}/_{64}$ inch) on each side of the stop which is intended to prevent the rotation of the rings.

B. — *Piston valves.*

As in the case of the pistons, it is essential that the piston spring rings are intended for tightness alone. The rings for guiding the valves must be returned or renewed as soon as they show appreciable wear.

When the valves are taken to pieces, they are cleaned so as to remove any trace of coom, and care is taken that the spring rings can be moved by hand perpendicularly to the rod.

When the valves are put in, care is taken that the play of 1 millimetre ($^{3}/_{64}$ inch) which according to the plans must exist between the ends of the rings is present.

FRANCE.

French State Railway. (System of the former French Western Railway.)

INSTRUCTIONS CONCERNING THE DRIVING AND THE MAINTENANCE OF SUPERHEATED-STEAM LOCOMOTIVES.

Before starting. — The maintenance of the tightness of the smoke-box is of much importance. The men must accordingly see that the door and the hopper are completely closed and that there is no reason for the entrance of air.

The automatic dampers of the superheater must be carefully kept clean, so as to be able to work freely.

These dampers must be normally kept closed when standing still, except during sweeping operations.

The oil pumps must be filled and tried by hand after each journey. With this object in view the control screws of the retaining valve must be opened and the crank of each pump is slowly turned until the oil comes out through the screw holes; then the latter are closed again.

Before the first start, heat up the cylinders until only dry steam comes out through the drain cocks.

The lubrication of the regulator, should this be considered necessary, is only to be effected with superheater oil.

When leaving the depot, go, as much as possible, with the drain cocks open and the valve gear with maximum cut-off, so that the valves may drive out the residues of oil and of scum which may have accumulated at the ports, and so that the ports may become fully heated.

While running. — Open the regulator progressively and take care that the pressure in the valve chests (high-pressure in the case of compounds) is markedly less than that in the boiler.

If possible do not close the drain cocks till the pyrometer indicates a temperature of at least 200° C. (392° Fahr.).

At the subsequent start, if the stop has been too long, the drain cocks can remain closed. They are to be opened while running if a sudden and great drop in the superheat shows that water has been carried over.

It is not of advantage with the superheater to have very much expansion. It is better to throttle by means of the regulator. In the case of non-compound locomotives, the cut-off must never be less than 20 per cent, and it is preferable to keep to an average of 30 per cent. In the case of compounds, the high-pressure cut-off should not be below 45 per cent.

With ordinary loads, in current service, it is desirable that the pressure in the high-pressure valve chests shall be less than 10 kilograms per square centimetre (142·23 lb. per square inch) in the case of boilers with an authorized pressure of 15 kilograms per square centimetre (213·34 lb. per square inch). Increase the cut-off if not enough power is obtained.

When the regulator is closed, the reversing gear is left in the same position as with the regulator open; if it were moved to the limit of its travel, there would be a risk of the valve jamming: this operation is only carried out after a stop, with a view to a future start. If however it is necessary to run for a long time with regulator closed, one can, after some moments, move the reversing gear slowly and gradually; it is however necessary to bring it back to the dead point in case of any knocking or jamming in the valve gear.

If the working of the valves leaves something to be desired, admit a little steam into the cylinders, and, as soon as it is possible, force the lubrication by turning the oil pumps by hand. In case of any damage interfering with the working of one of the mechanical lubricators of the high-pressure cylinders, close at once the dampers of the smoke chamber, so as to stop the superheating and continue running as with an ordinary locomotive using superheated steam.

The advantages of superheat increasing with the temperature, the latter has to be kept up, as far as possible, to its highest degree by a rational management of the fire and by proper manipulation of the variable blast-pipe. In the regular running, the needle of the thermometer must not fall below 320° C. (608° Fahr.). It must not indicate, except for a very short time, a temperature of over 350° C. (662° Fahr.). In case this should happen without it being possible to reduce the exhaust, close the dampers of the smoke chamber gradually and partially.

In order to obtain the best results with superheated steam, the attention of drivers is called to the necessity of maintaining a sufficient depth of fuel, well alight, covering the whole grate, supplied with coal at frequent intervals, putting in a moderate number of shovelfuls.

Insufficient superheat may equally be the result of too great a depth of fire not well alight at the surface, as of too small a depth, allowing air to pass through. It may also be due to want of cleaning of the superheater tubes and to the presence of obstructions at the tube-plate. Too high a water level can produce the same effect if water is carried over.

After running. — The examination of the mechanism presents no special features; the rods of the valves and pistons are to be examined more particularly to see that there is no chance of seizing.

The sweeping out of the upper and lower tubes has to be effected with great care; as regards the upper tubes containing the superheater elements, this is best effected from the back, from the fire-box, not forgetting first to open to their fullest extent the dampers of the smoke chamber by means of the lever placed outside near the smoke-box. The attention of the depots its particularly drawn to the absolute necessity of looking after the very complete cleaning of the superheater elements, or else their utilization will be reduced very quickly. The upper tubes must have any cinders removed which may have become lodged between the superheater tubes; the back tube-plate must be carefully cleaned and any beginning obstructions are to be removed; any clinker which tends to adhere to the back ends of the superheater is to be carefully removed by means of hooks, and taken out at the fire-box side.

Locomotives using superheated steam have, as already stuted, to be lubricated very perfectly; but it is advisable from several points of view that the internal lubrication should not be excessive. The examination of the valves, pistons and of their rods will enable the depots to ascertain this and to give the drivers useful advice as to the adjustment of the oil pumps.

Periodical examinations.

Apart from the usual and regulation examinations, the following should be attended to :

The valves and pistons should be carefully examined and thoroughly cleaned, as far as possible every six weeks and at least every two months, in the way specified below. The rods, the packings for the front guides of the piston rods, the rods for operating the dampers and the lubricators are also to be examined.

Superheater. — The superheater elements must be taken out and examined with care, and thoroughly cleaned at each change of the wheels and at every general overhaul at the workshops, at the least. If there is occasion for a hydraulic test, of the whole or of part of a superheater, under the conditions which will subsequently be specified, the test pressure is the same as in the case of the boiler. The superheater tubes, before being put in place again, are coated by hand with a thin layer of coal tar.

Valves. — Apart from the examination of the valves, specified above, a minute examination of the valves will be made at each change of the wheels and at every general overhaul. The valves are to be handled with care, so as to avoid any knocks on the rubbing surfaces or fracture of the spring rings. If the spring rings adhere and the valves are very dirty, it is necessary to take them to pieces, to clean them thoroughly and to make certain that the rings are detached. Remove from the body of the valve any deposit of carbonized oil which may be adhering to it.

When the spring rings are put in place again, take care that they have the necessary vertical play. If the surfaces of contact of the spring rings and the valves are no longer quite true, re-turn them to a slight extent.

The guide rings of the valve rods must be examined and changed as soon as the need for this becomes apparent, so that the body of the valve may not bear on its spring rings.

Carefully examine the ports and clean them, and if necessary clear the oil passages.

Take care that the valves are perfectly free after they are in place again; pay great attention to the adjustment.

The joints of the plates of the valve must not be made of any material which is elastic or has an appreciable thickness, in order to avoid any skewness in the grinding.

Cylinders and pistons. — Remove the bottom of the cylinders, take out the pistons, remove every trace of coom or of oil residues; clean the grooves in the spring rings and the grooves they occupy in the piston, and if necessary round the corners. Never leave out of consideration that the piston disks must never touch the cylinder walls and must be completely supported by the slide bars and the front guide.

The bronze tail-rod guides must be renewed as soon as they show any appreciable play. The depots should have a stock of these guides.

The stuffing boxes similarly are only there to provide tightness and must never support the rod; their lateral freedom has to be checked whenever there is opportunity, and any worm rings must be replaced. When mounting again, see that the stuffing boxes can turn a little about the rods, have the longitudinal elasticity necessary and are not jammed by having a ring which is too large.

The safety and atmospheric valves must be taken off and examined; any valves which are not tight must be reground.

Pyrometer. — Each time the locomotives come to the workshops, the pyrometer is to be taken off and sent to the maker, for examination and verification.

Midi Railway.

Instructions for the driving and the maintenance of locomotives fitted with the Schmidt superheater in the smoke tubes.

Before the locomotive is used for a train, the driver warms the cylinders by sending steam in, and he opens the drain cocks to allow the condensed water to escape.

When starting, he opens the regulator very slowly, after having ascertained that the hand-wheel for adjusting the superheater is in the fully-open position. After starting he only closes the drain cocks definitely when the pyrometer indicates a pressure of about 200° C. (392° Fahr.). The water-level in the boiler must not be too high at the moment of starting.

While running, the fire must be managed in such a way that the temperature indicated by the pyrometer remains at about 320° C. (608° Fahr.). In order to obtain this result, there must be on the grate a layer of coal sufficiently deep, well spread and well alight; the fuel should be put in frequently and in small quantities and the boiler should be fed in as continuous a manner as possible.

Insufficient superheat may be due to :

Bad firing;
Absence or bad condition of the arch;
Want of cleaning of superheater;
Excess of water in the boiler, and generally, all the causes which may lead to water being carried over;
Want of tightness of the smoke-box door.

A sudden drop in the temperature indicates that water has been carried over into the super-

heater and the cylinders. It is then necessary to open the drain cocks. When water is frequently carried over, it is a sign that the boiler requires to be washed out.

The temperature must not exceed 350° C. (662° Fahr.); if this limit is exceeded, the superheat must be reduced by partly closing the dampers by means of the hand-wheel for regulating the superheater.

The cut-off must not be less than 20 per cent and the regulator must not be too fully open.

The driver must pay the greatest attention to the proper working of the lubricators for the cylinders.

It is absolutely prohibited to use any oil for lubricating the cylinders of superheated-steam locomotives except that specially provided for the purpose.

When running with regulator closed, it is unnecessary to bring the reversing gear to its limits, owing to the existence of special arrangements for limiting the compression in the cylinders. This operation is not necessary except after a stop, with a view to a subsequent start. When after running with regulator closed, the driver opens the regulator again either for forwards, or with reverse steam, he must see that the connexion between the two sides of the piston is shut off.

When running with reverse steam, the driver must take care that there is sufficient injection. When changing from reverse steam to normal running, he must open the drain cocks under the same conditions as at starting.

After each trip, the large smoke tubes must be swept out by means of the compressed-air jet, and the dampers of the superheater must be carefully cleaned when the smoke-box is cleared out.

The safety valves and the atmospheric valve of the cylinders, as well as the devices for connecting the two sides of the piston when running with regulator closed, must be carefully cleaned.

Paris-Lyons-Mediterranean Railway.

INSTRUCTIONS FOR DRIVING THE LOCOMOTIVES USING SUPERHEATED STEAM ON THE PIELOCK SYSTEM.

The fire must never be lit on such a locomotive till after it has been ascertained that the boiler and the superheater are full of water.

Filling the superheater. — The superheater being empty, the boiler is so equally. The cock R is open (fig. 16), the handle of the cock V is horizontal and turned towards the back of the locomotive (position for filling).

The boiler is filled with water at least up to the regulation level. Then wait half an hour to allow the superheater to become completely filled.

The level of the water in the boiler is then again checked.

Raising steam. — The fires are then lit. As soon as the pressure reaches 1·5 to 2 kilograms per square centimetre (21·33 to 28·45 lb. per square inch), the cock R is closed, and the handle of the cock V is slowly turned towards the front of the locomotive (position for emptying). The water contained in the superheater escapes, mixed with steam.

As soon as only steam comes out, which is readily recognized by the noise the latter makes in escaping, the handle of the cock V is placed and turned so that it points vertically downwards (position for running).

The preparation is then continued as in the case of an ordinary locomotive.

Supervision while running. — While running, the superheater requires no special care; all that is necessary is to observe from time to time the indications of the pyrometer, both before as well as while running; this is the sole means for controlling the proper working of the superheater. A drop of temperature of about 20 or 30° C. (36 or 54° Fahr.) below the normal superheat temperature, the spitting of the cylinders showing that water has been carried over, a comparatively-great consumption of water in the boiler, all those show want of tightness or some other defect in the superheater. Any such observations are to be reported to the head of the depot, as soon as this is reached.

Checking the tightness of the superheater. — After a longer stop while in steam, and before starting, this tightness can be checked by means of the three-way cock V. With this object in view, the cock is carefully placed in the position for emptying, which results in the outflow of the water which has entered. If this outflow is at all copious, this shows imperfect tightness; the superheater must then be examined.

Such trials should only be made at low pressures and when standing over a pit.

Reserve service and standing in steam. — When the locomotive is used for a reserve service or is standing in steam, the superheater must never be filled with water.

Stabling the locomotives not in steam. — On the contrary, each time the fire has been drawn, the superheater must be filled with water in order to avoid the oxydation of those parts of the smoke tubes which are included in the chest, owing to the complete cooling of the boiler or of a prolonged stabling of the locomotive in a cold condition.

For this purpose the following method is adopted :

1° The locomotive is placed at the exact spot where it is to be stabled, for after filling the superheater, the regulator must not again be opened; only water would be sent into the cylinders;

2° Taking into consideration that the superheater has a capacity of about 500 litres (110 English gallons), care is taken that the level of the water in the boiler is sufficiently high;

3° The handle of the cock V is placed in the position for filling and the cock R is opened;

4° The boiler is fed as and when required to replace the water taken by the superheater.

Emptying the boiler. — The superheater must never remain full when the boiler is being emptied. Consequently when the boiler is emptied for washing, repairs, etc., the superheater is at the same time emptied, by placing the cock V in the position for emptying.

When this operation is finished, the cocks R and V are placed in the position for filling. This makes it impossible to forget to fill the superheater when filling the boiler.

The principle of this apparatus consists in the utilization of part of the exhaust steam by making it pass through a nest of tubes placed in the heater so as to heat the water coming from the tender and circulating around the tubes in question, to a temperature which may attain about 95° C. (203° Fahr.).

This water is then sent into the boiler, as required, by a special hot-water pump.

Before starting, the driver must check that :

1° The cock for taking water, right side of the tender, is well open;

2° The heater is full of water;

3° The hot-water vessel contains plenty of air and that the drain cock at the bottom of it is closed;

4° The stop-cock for the valve box on the right side of the boiler is well open.

After starting, as soon as the regulator is open, the driver opens the flap valves for the exhaust steam, by turning the handwheel operating them in the direction opposite to that of the hands of a watch.

He adjusts their opening so that the pyrometer indicates a temperature of about 90 to 95° C. (194 to 203° Fahr.).

He gradually starts the hot-water pump.

He then sees that the pressure gauge connected with the hot-water vessel rises to about $^1/_2$ kilogram per square centimetre (7 lb. per square inch), above the boiler pressure.

He need not consider the jumping of the needle of this pressure gauge, which occurs at each stroke of the pump.

He adjusts the working of the pump in such a way that the level of the water in the boiler remains practically constant.

If the temperature indicated by the pyrometer rises to 100° C. (212° Fahr.), there is spitting of steam and of water through the two tubes placed along the chimney; he then reduces the opening of the flap valves; and vice versa if the temperature indicated falls below 90° C. (194° Fahr.) or thereabouts.

It is to be understood that it is advantageous to feed continuously while the regulator is open; once the latter is closed, the heater no longer receives steam and consequently the temperature of the water pumped falls rapidly.

On arrival, the driver closes the flap valves and fills up the boiler, if necessary, by means of the Giffard injector; the object of this is to make sure that the latter is always in proper working condition in case of any damage to the hot-water pump.

If the locomotive is to stand still for more than three hours, he opens the drain cock at the bottom of the hot-water vessel, so as to drain this.

He is then certain, when starting, that the latter is full of air.

In winter, if the locomotive is exposed to frost while standing still, the driver closes the stop-cock on the right side of the boiler and the water cock on the right side of the tender; he then opens all the drain cocks placed at the low points of the hot-water and cold-water piping, of the hot-water pump and of the heater, so as to empty them completely.

Finally he uncouples the joint on the right side of the tender.

If he wants to heat the water in the latter, he then only uses the heater cock on the left side.

When starting, he does these operations inversely, last opening the water cock on the right side of the tender.

He then checks that the heater is properly filled with water, by opening either the drain cock or the hot-water pipe, or that placed at the bottom of the hot-water pump, and by seeing that the water issues freely through these cocks.

[621 .133.3 & 621 .134.3]

REPORT N° 7

(Russia)

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CHAPTER I.

Water-tube boilers.

a) *Results obtained on the Moscow-Kazan Railway.*

The protracted and expensive repairing of boilers, which makes it necessary to lay up the locomotives, after they have been some time in use, for weeks or even months, at the chief repairing shops, led the reporter, more than twelve years ago, to consider the possibility of replacing the usual locomotive fire-box by one of new type, with water tubes. The experiments begun with this object in view were however not yet completed when a former colleague of the reporter, engineer J. Brotan, brought forward his water-tube fire-box, which had been very carefully thought out and logically designed.

Much to the satisfaction of the reporter, this made further work unnecessary, and rendered it possible to proceed immediately to practical tests of a completed design which aimed at the object in view.

After the many protracted formalities, which in this country obstruct the introduction of any thing new, had been overcome, it was possible, in the year 1904, to begin the construction of two experimental boilers for 0-4-0 goods locomotives, one being intended for locomotive A H No. 447; and this has now been in use for two years, without interruption.

When the authorization for the construction of these boilers was given, several

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of the State engineers expressed misgivings on the subject, but the boilers have kept in very good condition and have required practically no repair.

Leaks very seldom occurred and were easy to remedy; the only repair of any magnitude consisted in replacing one water tube which had been burnt through, by a new one.

The cause of this damage was want of care when washing out the boiler; the arrangement of this boiler is shown in figures 24 to 28, but it is no doubt well known generally by now. A large number of small pieces of scale had come off the tubes, and had collected in the foundation tube below the inflow; this obstructed the circulation of the water in the tube and caused the trouble.

Only one day was required at the workshops for replacing this tube (1).

It may accordingly be considered as established, that the Brotan boiler in fact requires but few repairs, and that these repairs require only comparatively very little time.

The results obtained on the Moscow-Kazan Railway also show that Mr. J. Brotan's assertion, that a boiler of this design works more economically than the ordinary locomotive boiler, can be considered fully proved.

The reports of the statistical section of the locomotive department showed that the Brotan boilers gave an economy of 14·43 per cent in the coal consumption; this result was so surprising that the administration determined to check it by a number of carefully-executed trial runs.

This work was carried out by Mr. R. Haenelt; he used, for purposes of comparison, locomotive A H No. 420, which was in very good condition and which, apart from the boiler, was of the same design.

The experimental runs took place in April 1909 on the Sokolniki-Riazan line, 183 versts (121·3 miles), and gave the following results :

Designation and number of the locomotive.	Coefficient of the Sokolniki-Riazan line.	Coal consumed per 1,000 pood-versts (per 1,000 English ton-miles).	Heat units utilized in boiler per kilogram of coal (British thermal units per lb.)
0-4-0 A. H. 420	6 63	1·072 (3·619)	5,490 6 (9,883)
0-4-0 A. H. 447 with Brotan boiler. . . .	5·46	0·913 (3·082)	5,525·2(9,945·4)

These results not only prove the superiority of the Brotan boilers, but also confirm the coal economy observed by the locomotive department; for these figures show an economy of 14·8 per cent.

In consequence of these results, the administration decided to equip fifteen 1-4-0 superheated-steam passenger locomotives, now being built, with Brotan boilers (see

(1) Locomotive-inspection report of the Moscow-Kazan Railway, 8 December 1908. No. 17713/2.

figs. 26 to 28); each of them is to have twenty-four smoke tubes, in accordance with the principles explained in section II.

In external appearance the boilers of these new locomotives will materially differ from those shown in figures 24 and 25. As figures 26 to 28 show, the upper barrel is in this case eliminated, but the back ring of the barrel is coned, and in this way room is obtained for the steam collector, into which the fire-box water-tubes lead from below.

The foundation tube, which occupies the place of the fire-box foundation ring, has as its chief function that of supplying water to the fire-box water-tubes in order to replace that which is evaporated, from the barrel, with which it is connected in this case by two large tubes (up till now only one tube was used). The result is a very quick circulation of the water in the Brotan boiler, and this, it is stated, makes it more difficult for scale to deposit, even if hard water is used. The Moscow-Kazan Railway cannot however say whether this statement is true, as it fortunately has good water at its disposal.

Having two tubes connecting with the barrel has made it possible to avoid connecting both longitudinal sides of the foundation tube. This is an appreciable improvement, as experience has shown that the flange joints of the foundation tube are those points of the boiler where it is most difficult to prevent leakage. In the present case the foundation tube will only consist of four parts, which are united by three flange joints into one whole (1).

As the water enters the fire-box water-tubes from below, steam will be able to rise very freely without forming vortices; and as moreover the mixture of steam and water, which is in the tubes, has a materially-lower specific gravity than the entering water, the circulation of the water is much facilitated in this design. The quicker and more economic production of steam in the Brotan boiler has been attributed to this circumstance, together with the thinner fire-box walls. On the other hand it is shown, in appendix I, that the thickness of the walls of the heating surface is of quite subsidiary importance; consequently the more economic working of the Brotan boiler can only be attributed to the better circulation of the water and to the greater direct heating surface which results from the circular cross-section of the tubes and from their staggered arrangement.

If in order to calculate the production of steam, we adopt the method indicated by Professor O. Grove, and assume the fire-box heating surface replaced by an equal tube surface, we have to take into consideration that it is the radiant heat which has the most effect in the fire-box; accordingly we must replace k, the coefficient representing the amount of heat passing through the walls of the tube surface proper, by another and a large coefficient.

The equation :

$$K = 54 + 0{\cdot}514\,(T_0 - t_0)\,\frac{R}{H_d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

(1) During the construction, it was found possible to make the foundation tube on each side of one piece, without joints. Accordingly only one flange joint is required.

gives a value for this larger coefficient of heat transmission K which well agrees with the experimental results; in this equation, the first term $54 = k$ represents the coefficient of heat transmission for the tube surface, as explained in appendix I. The second term of the right side of the equation represents the radiant heat. T_0 is the temperature of combustion, t_0 is the temperature of the water, and $\frac{R}{H_d}$ is the ratio of the grate area to the heating surface of the fire-box, no deduction being made in the latter for the smoke-tube openings.

According to appendix II, the reduction of temperature inside the fire-box is expressed by the equation :

$$(M + 2Nt_0) \log_e \frac{T_0 - t_0}{t - t_0} + 2N(T_0 - t) = KH_d \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The product on the right side applies to fire-boxes of the ordinary construction, just like equation (1), and we will now examine how the whole value KH_d can be determined for a Brotan fire-box.

As the action of the radiant heat is not affected whether the vertical fire-box wall is flat or corrugated, we will in the first place determine that in calculating that part of K, which expresses the radiant heat, the ratio H_d is to be assumed as if the ordinary construction were under consideration, that is to say $\frac{R}{H_d}$ is to be determined as if the fire-box walls were of the same dimensions as in reality, but flat. If we denote the heating surface of the fire-box so calculated by H_d, we have in equation (2) instead of the product KH_d the product :

$$KH'_d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which represents the value of the temperature function on the left side of the equation, if we had to deal with a fire-box of ordinary kind having the same dimensions as the Brotan fire-box in question. But it is evident that the first term on the right side of equation (1) applies to the whole extent of H_d of the heating surface of the Brotan fire-box, and consequently we must add to KH'_d

$$54 (H_d - H'_d) = k (H_d - H'_d) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

in order to obtain the right side of equation (2) for a Brotan boiler.

Consequently the equation applying to the latter is

$$(M + 2Nt_0) \log_e \frac{T_0 - t_0}{t - t_0} + 2N(T_0 - t) = KH'_d + k (H_d - H'_d) \quad . \quad . \quad . \quad (5)$$

In this equation, according to appendix I, $k = 54$ and $H_d - H'_d$ is the difference between the heating surface of the fire-box of the Brotan boiler and the heating surface of the assumed fire-box of the same linear dimensions but of ordinary construction.

In the case of the boiler of the Mallet superheated-steam locomotive (figs. 21 to 23) considered in section II, the difference $H_d - H'_d = 4{\cdot}2$ square metres (45·2 square feet) and consequently $H_d = H'_d + 4{\cdot}2 = 14 + 4{\cdot}2 = 18{\cdot}2$ square metres (195·9 square feet). Accordingly $KH'_d + k(H_d - H'_d) = 2{,}758 + 226{\cdot}8 = 2{,}984{\cdot}8 \sim 2{,}985$.

In the case examined [1], with $M = 4{,}102{\cdot}344$, $N = 0{\cdot}53856$ and $T_0 = 1{,}335°$, the hot gases are cooled in the fire-box down to $T_r = 877°$. In order to determine the cooling in a Brotan fire-box of the same external dimensions, we have only to make the left side of equation (5) equal to 2,985. This gives for T'_r

$$T'_r = 837{\cdot}7 \sim 838.$$

The temperature at the tube-plate is here exactly 39° lower than with a boiler of ordinary construction. Consequently according to equation (13), the amount of heat absorbed by the fire-box is

$$W_r = 4{,}102{\cdot}344\,(T_0 - T'_r) + 0{\cdot}53856\,(T_0^2 - T'^2_r) = 2{,}620{,}500 \text{ heat units}$$

as compared with 2,424,487 with the ordinary boiler, or 196,103 heat units more.

Let us now assume, as indeed is really the case with the Mallet wet-steam locomotive of the railway, that a tube heating surface of 186 square metres (2,002 square feet) follows the fire-box. Then, to determine the smoke-box temperature of the locomotive with ordinary boiler, we have

$$(M + 2\,Nt_0)\log_e \frac{T_r - t_0}{t - t_0} + 2\,N\,(T_r - t) = 186 \times 54 = 10{,}044 \quad . \quad . \quad . \quad (6)$$

with $T_r = 877$. This gives us for the temperature of the smoke-box

$$t = T_s = 270°.$$

In the case of the Brotan boiler $T'_r = 838$ and accordingly equation (6) gives

$$T_s = 263°.$$

We see that the difference between the final temperatures is but small, and hence that the theoretical coal economy obtained with the Brotan boiler can not be large. Taking equation (15) for the heat taken by the smoke tubes as basis, we accordingly find that the heat taken up by the latter in the ordinary boiler is

$$W = 4{,}102{\cdot}344\,(877 - 272) + 0{\cdot}53856\,(\overline{877}^2 - \overline{272}^2) = 2{,}756{,}295{\cdot}41 \text{ heat units.}$$

In the Brotan boiler, the heating surface of the smoke tubes would only utilize

$$W' = 4{,}102{\cdot}344\,(838 - 263) + 0\ 53856\,(\overline{838}^2 - \overline{263}^2) = 2{,}695{,}410{\cdot}51 \text{ heat units.}$$

The greater efficiency of the Brotan fire-box thus results in a smaller efficiency of the heating surface of the smoke tubes.

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[1] See chapter 2, section II.

If we add the quantity of heat absorbed by the smoke tubes to that utilized by the fire-box, we obtain :

Ordinary boiler	2,756,295 + 2,424,487 = 5,180,782	heat units.
Brotan boiler	2,695,411 + 2,620,500 = 5,315,911	—

The difference accordingly amounts to 135,129 heat units per hour, or 2·12 per cent of the heat produced on the grate (6,354,202 heat units).

This savings corresponds to the assumption on which the calculation is based, that the direct heating surface of the Brotan boiler exceeds by 4·2 square metres (45·2 square feet) that of the ordinary fire-box of 14 square metres (150·7 square feet), or by about 29 per cent; and this corresponds to the new simpler designs, with smooth front and back wall.

The fire-box of a Brotan boiler can however, for the same external dimensions, have up to 50 per cent more heating surface, and in this case the economy in fuel is correspondingly larger.

If we now try to determine why there is a much greater saving in fuel both during trial runs as well as in practice, we find, among different reason, the great superiority of the Brotan boiler while getting up steam or while running with regulator closed, and also when the boiler has much work to do, particularly in cases where the heat transmission coefficients k and K in boilers of ordinary construction are reduced by the formation of scale, while this reduction only applies in the case of the Brotan boiler to the smoke-tube heating surface.

When very little steam is generated (standing still and running downhill), one of the preliminary conditions for K = 54, a certain circulation of the water in the boiler, no longer exists and bubbles of steam remain attached to the heating surface and check the transmission of the heat.

It probably also happens, when much work is done, in the case of fire-boxes of ordinary design with in sufficient circulation of water, that the heat transmission is made more difficult, particularly when the fire-box water-spaces are too small; so that the bubbles of steam cannot escape sufficiently quickly to the top.

In any case, the question of the reasons for the comparatively large coal-economy of the Brotan boiler remains an open one until further trials have been made on the experimental section (fig. 16), and the reporter hopes to give further information on the subject later on.

Lastly it must be mentioned, that the Brotan boilers at first showed considerable tendency to leaking at the tube joints. This was over come by expanding copper rings, $^1/_2$ millimetre ($^1/_{64}$ inch) thick, into the holes of the tube-plate before introducing the tubes.

b) *Results obtained on other Russian lines.*

Among the locomotives with Brotan boilers, on other Russian lines, we have to mention the two 0-4-0 goods locomotives Nos. 675 and 708 running on the South Eastern Railway since December 1907.

The design of the boilers of these locomotives is that shown in figures 26 to 28; that is to say, the barrel consists of one conical and two cylindrical rings, while the fire-box tubes are expanded at the top into the cylindrical steam collector which is riveted to the iron tube-plate. The only difference is, that with the boilers of the South Eastern Railway the connexion between the foundation tube and the barrel consists of one tube only, having a diameter of 202 millimetres (7 $^{15}/_{16}$ inches). The chief particulars of these boilers of the 0-4-0 goods locomotives, with Brotan boiler, of the South Eastern Railway, are as follows :

Working pressure	13 kilograms per square centimetre	(185 lb. per square inch).
Number of smoke tubes	208.		
Length between tube-plates	4,450 millimetres	(14 ft. 7 $^{3}/_{16}$ in.).
Heating surface, smoke tubes	133·8 sq. metres	(1,440·2 sq. feet).
— — fire-box	15·2 —	(163·6 —).
— — total	149 —	(1,603·8 —).
Grate area	1·94 sq. metre	(20·8 —).
Weight of boiler, empty	13·85 tons	(13·63 English tons).

The two locomotives equipped with Brotan boilers, Nos. 675 and 708 were at first used in the Orel-Werchowje district, where there are gradients of up to 9 per mil on a section 85 versts (56·5 miles) long, and where the feed-water has a hardness of 13 to 17°. The trains weigh about 700 tons (689 English tons) in summer and 640 tons (630 English tons) in winter, weight of locomotive and tender included. In November 1908 the two locomotives were transferred to the Tschertkowo-Sulin district, on which the conditions are less favourable, as there are many gradients of from 8·9 to 10 per mil and the feed-water available has a hardness of 20 to 35°.

Working under these conditions, the locomotives with Brotan boilers have given excellent results in every respect (1); it is stated that the boilers have excellent power of evaporation and great efficiency, so that it is easy to make up for lost time. Then they are also very economic as compared with other locomotives of the same class.

As regards the coal economy, the following table is given :

Type of locomotive.	Coal consumed, in poods (in lb.)	Versts (miles) run.	Coal consumed per locomotive-verst, in poods (in lb. per locomotive-mile).
Nos. 675 and 708, with Brotan Boilers.	57,940 (2,092,360)	45,668 (30,271)	1·268 (69·121)
Other 0-4-0 locomotives.	321,810 (11,621,390)	205,817 (136,421)	1 563 (85·186)

(1) See Shmailowitsch, « Brotan boilers on the South Eastern Railway » (Russian), in *The Engineer*, Kiew, May 1909.

The saving in coal of the locomotives with Brotan boilers accordingly is :

$$\frac{1{\cdot}563 - 1{\cdot}218}{1{\cdot}563} \times 100 = 18{\cdot}87 \text{ per cent.}$$

It has however to be noted, that the administration does not attribute the whole of the coal economy to the Brotan boilers; for the locomotives Nos. 675 and 708 were at the same time modified in other ways. The Joy valve gear of the Russian standard 0-4-0 goods locomotives was replaced by Heusinger valve gear, and the ordinary flat slide valves of these locomotives were replaced by balanced slide valves of the von Borries type.

The railway, on the basis of other experiments, attributes a coal economy of 9 to 10 per cent to these alterations in the design; this leaves an economy of 9 to 10 per cent in favour of the Brotan boiler.

Among the troubles which occurred with the Brotan boilers in practice the following were observed :

1° Leaks at the flanges of the foundation tube, and of the tube connecting it with the barrel;

2° Leaks at the smoke tubes;

3° Leaks at the fire-box water-tubes at the points where they were expanded with the steam collector. In one case a leaking fire-box tube, which had not been properly expanded at the right time, and consequently became corroded, had to be replaced.

This renewal however only took a few hours and gave no difficulty. The tube taken out, which had been six months in use, had a layer of scale from 0·75 to 1 millimetre ($^1/_{32}$ to $^3/_{64}$ inch) thick.

The administration of the South Eastern Railway consequently considers the mere washing-out of the water tubes as not sufficing to remove the scale produced when hard water is used, and intends to use pneumatic hammers for removing the scale, such as are used by the Paris-Lyons-Mediterranean Railway for their Robert water-tube boilers.

The administration is however of opinion that these troubles can be prevented in part by small modifications in the design, easily carried out, and in part by proper attention; it sees in them no reason against the further use of boilers with Brotan fire-boxes.

The results obtained by the railways in question lead to the following conclusions :

1° With proper attention, the Brotan boiler works reliably and economically. The smaller amount of water consumed by locomotives equipped with Brotan boilers shows, contrary to earlier expectations in connexion with the formation of steam in these boilers, that drier steam is produced than by locomotive boilers of the ordinary pattern. This state can however also be attained by the use of better water-intercepting devices.

2° As the two tube-plates are riveted to the barrel of the boiler which does not give in the longitudinal direction, it appears that the smoke tubes are more rigid in the boiler than is the case in the usual system of construction; this gives them a tendency to leak. It is consequently advisable to have two or three corrugations rolled in one of the rings of the barrel;

3° Repairs found to be necessary in the Brotan boiler could be carried out easily and quickly; this is a positive advantage of this system of construction;

4° The Brotan fire-box gives the frame no support and consequently it is necessary to provide other stiffening for it;

5° The Brotan boiler works without doubt more economically than the ordinary boiler. The calculated coal economy is 2 to 5 per cent, but in practice it was found to be 10 to 14 per cent; the reasons for this discrepancy have not as yet been ascertained with certainty;

6° As the majority of boiler explosions are caused by a defective condition of the fire-box walls, the Brotan boiler may be looked upon from this point of view as safer;

7° The Brotan boiler is about 15 per cent cheaper than the ordinary boiler;

8° The results obtained show that the use of Brotan boilers is to be recommended.

CHAPTER II.

Superheaters and valve gear for superheated steam.

INTRODUCTION.

The first reliable information about the favourable results obtained in practice by W. Schmidt in Kassel in using superheated steam on locomotives, which the reporter received, was sent to him in 1899 by his friend, the late J. Besser, engineer, of Berlin. The reporter has also to thank this distinguished man, who for many years was the manager of the largest and most celebrated locomotive works in Russia, the Kolomna Works, and who contributed so much to the progress of locomotive construction in this country, for introducing him soon afterwards to the distinguished inventor and pioneer of the superheated-steam locomotive, Mr. W. Schmidt, with whom he has entered into close personal relations since.

The reporter was until then a decided advocate of compounding, and had contributed not a little to the progress of the compound locomotive in Russia, by the design of the $^4/_4$ standard goods locomotive (1) of the Moscow-Kazan Railway

(1) The Moscow-Kazan Railway alone possess 213 locomotives of this type. They have also been introduced on other railways.

(type AH), which proved to be a particularly economical type, both as regards coal consumption and cost of repairs; yet the reasons in favour of the introduction of superheated-steam locomotives seemed to him so weighty that in his capacity of member of the administration of the Moscow-Kazan Railway he at once proposed, without hesitation, the immediate construction of a $^3/_5$ locomotive for passenger and express service in order that the matter might be investigated more closely.

Thus it happened that the Moscow-Kazan Railway was the first to begin the use of superheated steam in this country, and the description of the progress of the superheated-steam locomotive on this railway is therefore the history of the introduction of superheated-steam working in Russia generally. On the other companies' lines, and more especially on the State lines, the recognition of the progress, which the superheated-steam locomotive represents, made such slow advances, that these railways, as will be seen below, have hardly had any experience of the subject.

The first difficulty, which had to be overcome, was obtaining the ministerial approval to the construction of the first experimental locomotive; for under the laws existing in Russia, even privately-owned railways may only construct their rolling stock according to designs approved by the State authorities. Fortunately this part of the matter was comparatively quickly settled, thanks to the enlightened interest which was shown by the president of the commission for approving new rolling-stock designs, State Councillor N. S. Stschukin; the railway administration was accordingly able to give the order for the locomotive in question to the Kolomna Works on 12 October 1901.

In designing the general arrangement and the details of this locomotive, which is entered in the locomotive list of the line as type Б. II., and received the number 181, the design of the $^3/_5$ passenger locomotive, type Б. Г., built by Henschel of Cassel, was followed as closely as possible; only those modifications were admitted which were made necessary by using superheated steam instead of compounding, and by the addition of the Schmidt smoke-box superheater.

The type last mentioned, Б. Г., with which the new superheated-steam locomotive was to compete, can in every respect be considered a successful representative of the class of two-cylinder compounds for passenger trains, particularly as regards a low coal-consumption; hence all the technical employees of the line were very interested in the results of the competition between the two types.

For the sake of completeness I give below the chief particulars of the Б. Г. compound locomotive built by Henschel of Cassel (see also fig. 1):

Passenger and express compound locomotive, Б. Г.

Diameter of cylinder, high pressure	500	millimetres	(1 ft. 7 $^{11}/_{16}$ in.).
— — low — . . .	730	—	(2 ft. 4 $^5/_4$ in.).
Stroke of piston	600	—	(1 ft. 11 $^5/_8$ in.).

Diameter of driving wheels	1,700	millimetres	(5 ft. 6 $^{15}/_{16}$ in.).
— of carrying wheels	1,030	—	(3 ft. 4 $^{9}/_{16}$ in.).
Smoke tubes, number	210.		
— — external diameter	51	millimetres	(2 inches).
— — length between tube-plates	4,550	—	(14 ft. 11 $^{1}/_{8}$ in.).
Height of centre line of boiler above rail-level	2,500	—	(8 ft. 2 $^{7}/_{16}$ in.).
Length of copper fire-box (at top)	2,225	—	(7 ft. 3 $^{19}/_{32}$ in.).
Width — — (above grate)	1,032	—	(3 ft. 4 $^{3}/_{8}$ in.).
Heating surface of smoke tubes (external)	153·07	sq. metres	(1,647·6 sq. feet).
— — of fire-box	12·75	—	(137·2 —).
— — total	165·82	—	(1,784·8 —).
Grate area	2·34	—	(25·1 —).
Working pressure	12 kilograms per square centimetre		(171 lb. per square inch.).
Wheelbase	7,840	millimetres	(25 ft. 8 $^{11}/_{16}$ in.).
Weight, empty	52,600	kilograms	(115,960 lb.).
— in running order	58,720	—	(129,450 lb.).

Load on rails:

Bogie 10,260 + 10,260 =	20,540	kilograms	(45,280 lb.).
Leading coupled axle	12,700	—	(28,000 —).
Driving axle	12,900	—	(28,440 —).
Trailing coupled axle	12,580	—	(27,730 —).
Total adhesive weight	38,180	—	(84,170 —).

I. — General Conclusions to be deduced from the Results obtained with the First Superheated-Steam Locomotive of the Moscow-Kazan Railway, with Schmidt Smoke-Box Superheater.

As we have already remarked in the introduction, the first superheated-steam locomotive of the Moscow-Kazan Railway (locomotive Б. II. 181) was equipped with a Schmidt superheater (see figs. 2 and 3), which was constructed in accordance with the rules and designs received from the inventor.

As it may be assumed that the design of the Schmidt smoke-box superheater is known generally, we will only add that in this particular case all the superheater tubes have the same diameter (38/30 millimetres (1 $^{1}/_{2}$/1 $^{3}/_{16}$ inches) and are arranged in four rows, which consist, counting from inside outwards, of 16, 14, 16 and 14 tubes each. Thus the whole superheater consists of 60 tubes, having an external heating surface of 31·068 square metres (334·3 square feet). The collectors are so arranged that the steam makes two circuits; the steam enters the right collector, which is divided by a cross partition into two chambers of equal size, so that the steam which enters the back chamber in the first place enters the thirty tubes which begin here, and after completing one circuit enters the left collector which is not divided. From this it is led by the thirty front tubes to the front chamber of the right collector, to which the tubes leading to the valve chest are connected. Thus

the steam coming from the boiler flows once through thirty tubes from the right to the left, and then through the same number of tubes from the left to the right, and thus completes two circuits. In addition, it must be mentioned that the two inner rows of tubes, as figures 2 and 3 show, are bent at their lower ends in such a way that they pass above the opening of the flue tube, while the third and fourth rows of tubes are below this opening.

The following are the chief particulars of the superheated-steam locomotive in question :

Superheated-steam locomotive **Б. II.** *181, for passenger and express trains (in external appearance this locomotive differs very little from type* **Б. Г.**).

Diameter of cylinders	520 millimetres	(1 ft. 8 1/2 in.).
Stroke of piston	600 —	(1 ft. 11 5/8 in.).
Diameter of driving wheels	1,700 —	(5 ft. 6 15/16 in.).
— of carrying wheels	1,030 —	(3 ft. 4 9/16 in.).
Smoke tubes, number	176.	
— — external diameter	51 millimetres	(2 inches).
— — length between tube-plates	4,550 —	(14 ft. 11 1/8 in.).
Height of centre line of boiler above rail-level	2,500 —	(8 ft. 2 7/16 in.).
Length of copper fire-box (at top)	2,250 —	(7 ft. 4 19/32 in.).
Width — — (above grate)	1,032 —	(3 ft. 4 5/8 in.).
Heating surface of smoke tubes (external)	128·304 sq. metres	(1381·00 sq. feet).
— — of flue tube (size 285/305 [11 1/4 in./1 ft.])	4·360 —	(46·92 —).
— — in contact with water	145·412 —	(1565·23 —).
— — in total	176·48 —	(1899·67 —).
Grate area	2·34 —	(25·18 —).
Working pressure	12 kilogr. per square centimetre	(171 lb. per sq. in.).
Wheelbase	7,840 millimetres	(25 ft. 8 41/16 in.).
Weight, empty	61,800 kilograms	(136,240 lb.).
— in running order	67,000 —	(147,710 —).

Load on rails :

Bogie 11,200 + 11,800	23,500 kilograms	(50,710 lb.).
Leading coupled axle	14,800 —	(32,630 —).
Driving axle	15,000 —	(33,070 —).
Trailing coupled axle	14,200 —	(31,300 —).
Total adhesive weight	44,000 —	(97,000 —).

That the locomotive is 8,280 kilograms (18,250 lb.) heavier is due partly to the addition of the superheater, but chiefly due to the cast-steel box and plate stiffening between the frame plates, usual on this railway. In the case of other compound locomotives procured from abroad, which had been built by Henschel & Son of

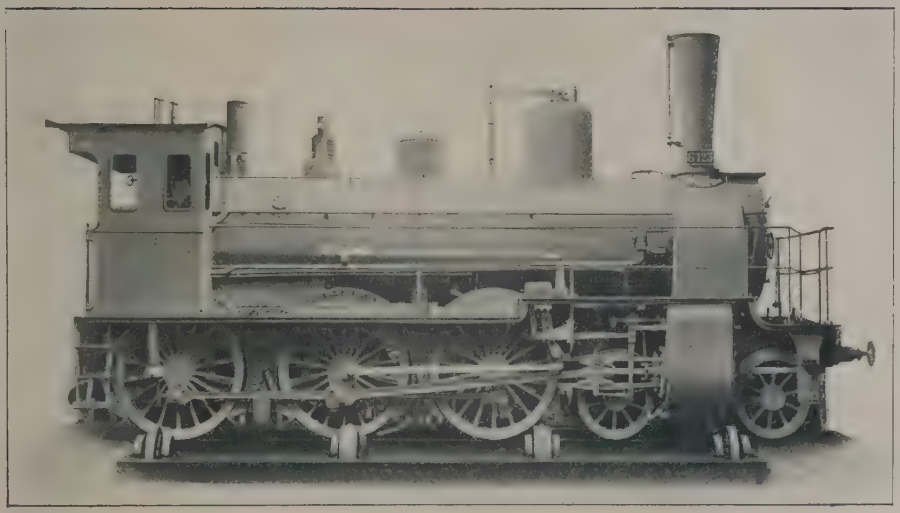


Fig. 1. — Moscow-Kazan Railway. — Ten-wheel passenger locomotive; 4809-4815.

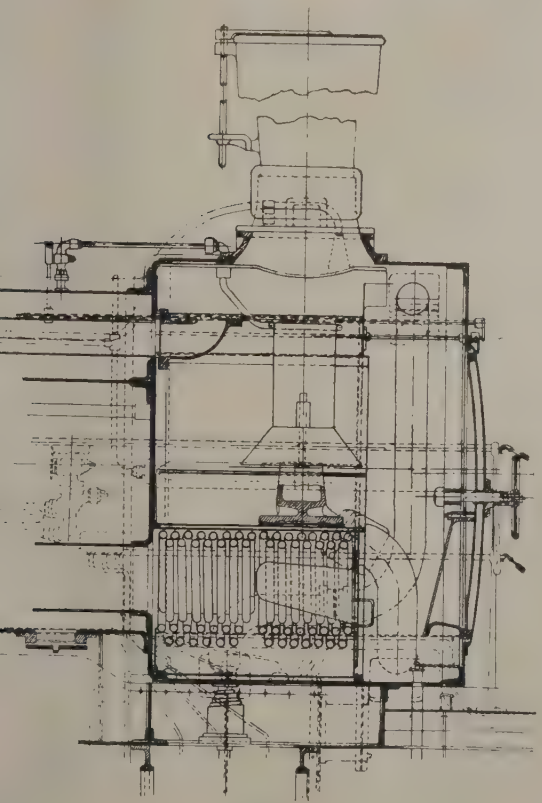


Fig. 2.

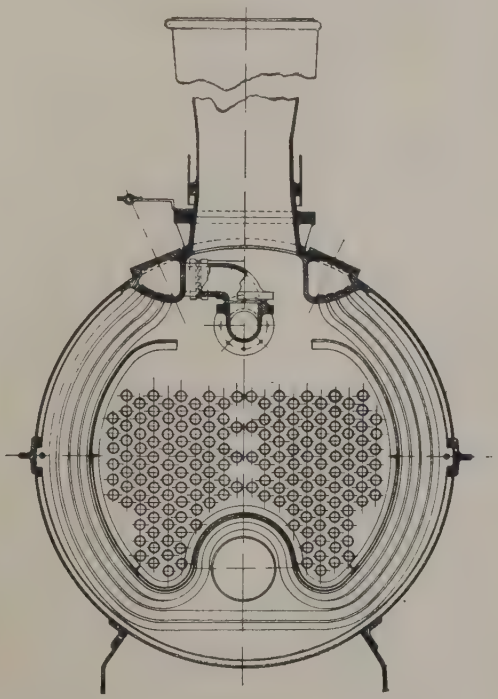


Fig. 3.

*

Fig. 5.

Fig. 4.

Cassel, these parts had been replaced by light riveted structures in order to save the high import duty. As the figures given show, of the additional weight of 8,280 kilograms (18,250 lb.), 2,460 kilograms (5,420 lb.) are carried on the bogie truck and 5,820 kilograms (12,830 lb.) go towards increasing the adhesive weight.

Very soon after this locomotive had begun running (1902), it showed its remarkable superiority as compared with the compound locomotives; this seems chiefly to depend on the following properties:

a) Much greater power. The new locomotive easily hauled trains which could only be hauled to schedule time with the greatest difficulty by the compound locomotive; even if very late, it made up the time with ease;

b) The elimination of all the disadvantages and defects of the compound locomotive, particularly that peculiar to the two-cylinder compound of having to start slowly, in spite of all sorts of ingenious starting devices; this results in much loss of time, especially in the case of a suburban service, and frequently leads to lateness, particularly in winter;

c) Smooth running and absence of knocking, particularly at high speeds, and consequent reduced fatigue of the bearings, cranks and rods. An advantage which the compound locomotive is often stated to possess, is that smaller forces act on the pistons; but this can only be true at low speeds. With higher rates of revolution, such as occur with wheels having the diameter of 1,700 millimetres (5 ft. 6 $^{15}/_{16}$ inch), usual on the railway, the pressure of the steam at the beginning of the stroke is undoubtedly too low in the case of the compound, and theory and experiment agree on this point, as Professor Radinger has shown in his classic work on the subject of steam engines with high piston-speeds.

The locomotives of the design described are distinguished by specially smooth running, even at speeds exceeding 100 kilometres (62 miles) per hour; as the speeds are increased and the admission reduced, the superiority of the superheated-steam locomotive becomes more and more apparent.

This circumstance is probably to be explained by the gaseous nature of the superheated steam, which results in much greater velocity in the passages and openings, which with small admissions are correspondingly contracted, and so produces fuller diagrams than in the case of saturated steam;

d) An economy of water of 25 to 30 per cent, as compared with the compound locomotive; consequently, the boiler being washed out the same number of times, the formation of scale is reduced and the boiler less affected. This also evidently results in a reduction in the cost of the water supply required;

e) An appreciable saving in coal. Mr. R. Haenelt, the head of the Moscow sheds, estimates this at 8 per cent, on the basis of trial runs made by him;

f) A much smaller dependence of the economic working of the locomotive on the difference between the normal work for which it is designed and the work it actually has to do in a given case.

The greater power of the superheated-steam locomotive, which has 5,820 kilograms (12,830 lb.) more adhesive weight, would indeed also be obtained in part, if a wet-steam compound locomotive having this larger adhesive weight were used. But the difference is that in the latter case the locomotive would work much more unfavourably, with a small load, than the superheated-steam locomotive, as the experience of all railways proves who have had to go in for heavier designs. On the other hand the economical working of the superheated-steam locomotive is much less dependent on the power, and its field of application is hence much less limited.

The reporter is of opinion, that this property of the superheated-steam locomotive is of great importance to railways, particularly in countries where the climatic conditions in the bad part of the year place obstacles in the way of the traffic which are difficult to overcome.

Neither the wet-steam twin locomotive, nor the wet-steam compound locomotive can have, in the case of a passenger locomotive designed for given work, any material excess of power above that required on the average, or else such a locomotive becomes too great for its average daily work and becomes exceedingly uneconomic.

Hence it follows that when wet steam is used, the locomotives are used to nearly their full power under normal conditions of traffic, and consequently no longer suffice in cases when even comparatively-little additional power is required; even small, accidental delays can no longer be made up, and if an additional carriage is attached to the train, or if there is an appreciable side wind, double heading becomes necessary.

The indefatigable inventor of the superheated-steam locomotive, W. Schmidt of Cassel, was the first who was able to eliminate this important disadvantage in railway working, by enabling us to build locomotives which work economically even when giving materially less than their full power.

This also enables the railway administrations to run the passenger trains with a punctuality which was unattainable formerly.

The advantages mentioned are of such importance for railway working, that the reporter at once felt certain that only quite unsurmontable difficulties or troubles would justify giving up the use of superheated steam, which had given such brilliant results at the very frist trial.

Locomotive No. 181 had already been in continuous use for six months, when the growth of the traffic induced the railway administration to obtain eight more express locomotives.

The reporter was of opinion that these should be superheated-steam locomotives, and as nothing special had so far happened to the first locomotive, he was able to get his opinion accepted.

As no time was available for working out any particular improvements, it was decided to build these locomotives exactly like locomotive No. 181, with the sole exception of the diameter of the cylinders, which was increased from 520 to 540 mil-

limetres (1 ft. 8 $^{1}/_{2}$ in. to 1 ft. 9 $^{9}/_{32}$ in.), so as to have reduced cut-offs, which are more favourable in the case of superheated steam.

Meanwhile complaints had also been made about the working of the first locomotive, which however were disregarded as it was impossible to work out new details without much loss of time.

The reporter thought that once the possibility of advantageously producing highly-superheated steam in the boiler of the locomotive had been proved, and that the use of superheated steam in the engine had proved satisfactory, any necessary minor improvements could be left till later on. His main object at the time was that the new express locomotives should not be built like the old type, as wet-steam locomotives.

It thus happened that these eight locomotives were also equipped with smoke-box superheaters, although W. Schmidt had already invented the smoke-tube superheater and strongly recommended it. As it happened, there was no time available for such radical alterations and the boilers were ultimately constructed according to a drawing which had in the meantime been sent by W. Schmidt, with slight alterations in the division of the tube-plates, and a newly designed smoke-box superheater.

The chief difference between this design and the former one is that the superheater does not consist of four (as shown in figs. 2 and 3) but of three (as shown in figs. 4 and 5) rows of tubes parallel to each other, only one of which is above the opening of the flue tube.

The steam from the boiler first enters the right collector, which is divided by a partition extending over its whole length into two chambers in such a way, that the steam only has access to the inner row of tubes (eighteen tubes). The steam flows through these into the chamber of the left collector, which contains the openings of the inner second row of tubes, and passes through the latter on again into the right collector, where the openings of the second (middle) and third (outer) rows of tubes are in one common chamber. The steam thus has free access to this last row of tubes and makes a third circuit from the right to the left steam collector, which is in connexion with the valve chest. The middle row of tubes includes seventeen tubes, the outer eighteen tubes, so that the total number of tubes is fifty-three.

The steam accordingly has to make three circuits; the path is 7·3 metres (23 ft. 11 $^{5}/_{16}$ in.) long, the available cross-section being given by eighteen or seventeen tubes respectively, which in this case have an internal diameter of 36·5 millimetres (1 $^{7}/_{16}$ inches).

On the first locomotive the steam flows simultaneously through thirty tubes having an internal diameter of 30 millimetres (1 $^{3}/_{16}$ inches), the whole path being only 4·3 metres (14 ft. 1 $^{3}/_{16}$ in.) long. The heating surface of the superheater is nearly the same in both cases (31·068 square metres [334·42 square feet] on locomotive No. 181 and 31·045 square metres [334·17 square feet] on the eight later locomotives).

The idea on which this arrangement is based is that the heat-transmission coefficient of the heating surface of the superheater must grow with the speed of the steam, and this justified the expectation that the new superheater would be more efficient than the superheater of locomotive No. 181.

The reporter was however so much satisfied with the working of the first superheated-steam locomotive that he only consented unwillingly to the use of the new design, and only did so on W. Schmidt's advice.

That the coefficients of heat transmission for any heating surface as a rule increase with the speed of the water and gas circulation is a well-known fact; and already in 1897 Professor Petrow of St. Petersburg, in a paper devoted to this subject, expressed the opinion that this property of heat transmission through boiler walls was not sufficiently taken into consideration in the case of locomotive boilers.

He therefore strongly recommended that in all cases where it was a question of utilizing heating surfaces as much as possible, the gas speeds should be as high as possible.

The reporter however, who was induced by this paper to investigate the question, had already then come to the conclusion that, although the heat transmission was largely increased by a higher speed of gas and steam, this increase of the coefficient of heat transmission became continually smaller as the speed increased and would finally become a vanishing quantity. (See appendix I, on the coefficient of heattransmission of the smoke tubes of locomotives.)

But the heat transmission is already very active with the first design of the smoke-box superheater (locomotive No. 181). When the express trains are hauled, the weight of water evaporated per square metre of heating surface rises to 60 kilograms (12·29 lb. per square foot) per hour; if we assume the steam to contain 3 per cent of water, this gives a coefficient of heat transmission $k = 60$ to 61 heat units per square metre (22 to 22·5 British thermal units per square foot) of external surface of the superheater tubes.

If we compare this figure with that found by equation (2), appendix I, for the heat transmission through the smoke-tube walls ($k = 54$), we must conclude that the steam in the case of the smoke-box superheater of locomotive No. 181 at high speeds, up to 18 metres (59 feet) per second, already takes up the heat from the internal surfaces of the superheater tubes not less energetically than the boiler water from the smoke tubes. Consequently the coefficient of heat transmission α_2, which corresponds to the amount of heat taken up by the steam flowing through the superheater tubes, must have such a high value that we can neglect $\frac{1}{\alpha_2}$ in equation (1), that in other words α_2 hardly contributes anything more towards the resulting value of $k = 60$ to 61. It is also clear that considering the greater thickness of the walls of the superheater (4 millimetres [$^5/_{32}$ inch]), the second term in

the denominator cannot have any appreciable influence on the value of k, so that here also, as in (1*a*), we have $k = \alpha_1$.

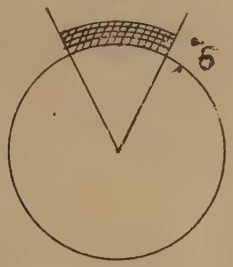


Fig. 6.

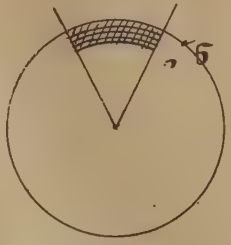


Fig. 7.

This conclusion has been fully confirmed by the results obtained with the superheaters, of altered design, of the locomotives Nos. 182 to 189; in spite of the speed which is increased inversely to the cross-section the steam has available for each circuit $\left(\frac{0{\cdot}0218}{0{\cdot}0178} = 1{\cdot}225\right)$, no increase in the amount of superheat was observed when an equal amount of work was done.

The higher value of $k = \alpha_1$ in the case of this superheater is remarkable, and difficult to explain. The cause of this phenomenon is probably only to be sought in the convex shape of the superheater tubes which are heated from the outside, where a longitudinal strip of the tube surface and a certain thickness σ of the adjacent layer of gas corresponds to a larger volume, so that the hot arriving particles of gas, and the cooled particles of gas leaving the surface, can travel past each other more easily that would be the case with a concave surface, like that of the smoke tubes. Apparently this effect increases with increasing velocity and becomes more marked the smaller the diameter of the tubes.

The results obtained accordingly justify the statement that *with the Schmidt smoke-box superheater, increasing the velocity of the steam beyond 18 metres (59 ft. $^{11}/_{16}$ in.) per second does not result in any appreciable increase in the efficiency.*

But this conclusion was only arrived at subsequently, after the locomotives had been four years in use; for until then these locomotives showed 30 to 35° C. (54 to 63° Fahr.) less superheat than the first locomotive No. 181 which had been equipped with the older pattern of superheater.

This circumstance was at first attributed by the locomotive department to the greater diameter of the superheater tubes, which had been increased from 30 to 36·5 millimetres (1 $^3/_{16}$ to 1 $^7/_{16}$ inches). The real reason was discovered by the reporter on a careful comparison of the drawings : the iron casing of the superheater was not large enough and the inner row of tubes was so near to this casing, that the circulation of the gases around the tubes of this row was considerably impeded, and consequently part of the superheater surface had lost much of its

efficiency. After this defect had been remedied, the amount of superheat obtained with these locomotives was the same as with locomotive No. 181, namely 290 to 300° C. (554 to 572° Fahr.).

As the first locomotive equipped with Schmidt smoke-box superheater has been in use for nine years, and the eight subsequent locomotives for over five years, doing hard work, without any troubles arising in connexion with the superheaters and the boilers, the conclusion appears to be justified, that this well-known system of construction is entirely reliable. It is true that on locomotive No. 181 three superheater tubes parted during the nine years, but this was merely due to incorrect treatment when expanding the tubes. That the railway subsequently adopted Schmidt smoke-box superheaters, was by no means due to any fault observed in those which were in use, but was exclusively on account of the superior properties of the new design, which included :

1° Greater efficiency;
2° Better distribution of the weight;
3° Simpler equipment;
4° Better accessibility;
5° Easier and quicker cleaning.

The results obtained with superheaters of this design in actual practice will be discussed later on; at present we will give some further particulars of the results obtained with the nine express locomotives mentioned.

Apart from the arrangement of the superheater and the greater heating surface (by 4 square metres [43·0 square feet]), the eight later locomotives only differ from locomotive No. 181 described, in having the diameter of the cylinders increased from 520 to 540 millimetres (1 ft. 8 $^1/_2$ in. to 1 ft. 9 $^9/_{32}$ in.). It seems however that the consequent advantage was until lately counterbalanced by the superheat being 30 to 35° C. (54 to 63° Fahr.) lower, so that all of these locomotives gave very similar results in practice.

Generally speaking, the management and the driving of the superheated-steam locomotive gave the employees, with a few very minor exceptions, practically no trouble from the very beginning; it must be however mentioned, in this connection, that metallic stuffing boxes were already in use before the introduction of the superheated steam.

In consequence of this, the locomotive department escaped the trouble and difficulty other Russian railways had in connexion with the introduction of these details of the superheated-steam locomotive, and even at present, these difficulties cannot yet be considered as overcome on most of the railways.

With the peculiar organization of the technical departments of most of the railways of this country, which have a tendency to attach most importance to the clerical work, it is very difficult to introduce details, which require great care as a condition for their proper and economic working.

It is evident that there can be no question of the introduction of metal packing for stuffing boxes where one is accustomed to see cross-heads working between slide bars with 3 or 4 or more millimetres ($^1/_8$ or $^3/_{16}$ inch) of play, where piston rods come from the lathe with visible grooves produced by the cutting tools, and which then, like a file, cut away the soft white-metal rings in a few days. Under such conditions, metallic stuffing boxes are very expensive, without fulfilling their function of keeping the piston rod tight, and this additional expenditure is often quite unjustifiably attributed to the superheated steam.

On the other hand there is no doubt, that if the cross-heads are kept in good condition and the slide bars are properly adjusted, and if the piston rods are properly ground on a suitable emery grinding machine, then the metallic stuffing box is in practice the most convenient and most economic, and wears the piston rod least.

Only one of the complaints made by the employees of the Moscow-Kazan Railway about the superheated-steam locomotives was justifiable, and that was the gradually-increasing leakiness of the piston valves with closed rings and the consequent loss of steam.

When on examining the reports of the management on the coal consumption of the superheated-steam and saturated-steam locomotives, we find very varying figures for the former, we have to attribute this solely and entirely to the loss of steam caused by these valves. If new piston valves are put in, the locomotive at once shows a remarkable reduction in the coal consumption; if on the other hand, the renewal of the piston valves has to be postponed for some reason or other, the coal consumption increases rapidly and there have been cases in which the superheated-steam locomotives for this reason alone consumed 12 per cent more fuel than the saturated-steam locomotives; in one case the excess was even 14 per cent.

These results finally induced the administrations, in the summer of 1907, to give up the use of piston valves with closed rings, in spite of their tempting simplicity and of the excellent results obtained with these piston rings on German railways (1), and to replace them by a simplified Schmidt piston valve having a diameter of 220 millimetres ($8\ ^{11}/_{16}$ inches) and spring rings. The space between the casing of the superheater and the tubes was increased at the same time. After these two alterations had been carried out, the superiority of the superheated-steam locomotive was not only made manifest by trial runs, which as a rule only apply to individual locomotives which generally are in specially good condition, but also by the statistical records of the whole class of locomotives, kept by the locomotive department. Thus we find that in July 1909, on the level section Moscow-Riazan, $^3/_5$ saturated-steam locomotives ran 53,177 locomotive-versts (35,247 locomotive-miles), consuming 159·83 poods (5,772 lb.) of naphta per unit of work (10,000 axle-versts [6,628 axle-miles]). On the same section, during the same months, the

(1) See GARBE : *Die Dampflokomotiven der Gegenwart.*

superheated-steam locomotives described ran 34,132 locomotive versts (22,624 locomotive-miles), consuming 147·32 poods (5,320 lb.) of naphtha per unit of work; the saving is thus about 8 per cent.

These and other similar results obtained with other classes of locomotives on the Moscow-Kazan Railway, in all probability justify the following conclusions:

The economy of the superheated-steam locomotive is largely dependent on the design of the piston valve. The Schmidt piston valve with so-called closed rings did not give good results.

According to the information we have received, the same conclusion has been arrived at by all the other Russian railways using superheated-steam locomotives.

These include the following railways :

1° The Nicolas Railway (St. Petersburg-Moscow);
2° The South Eastern Railway;
3° The Moscow-Windau-Rybinsk Railway (1).

In concluding this section, we may also mention that in spite of occasionally very great loss of steam by leaky piston valves with closed rings, the superheated-steam locomotives retained all their properties enumerated in the first part of this section under the letters *a* to *f*, with the exception of *e* and partly of *d*; this is without doubt a brilliant proof of the power of the boiler equipped with superheater and of the superheated-steam engine proper.

II. — **Results obtained with the superheated-steam locomotives equipped with smoke-tube superheater on the Moscow-Kazan Railway. Theoretical considerations.**

a) *Express locomotive* **Б. k.**

When the continually-growing traffic made it necessary, in 1907, to acquire ten more express locomotives, the question again arose whether these were to be wet-steam or superheated-steam locomotives. Taking into consideration the results obtained with the first nine superheated-steam express locomotives, as described in section I, it might be considered surprising that this question was at all raised, were it not that during that time very unfavourable results had been obtained with $2 \times 0 - 3 - 0$ Mallet superheated-steam locomotives. Unfortunately the reporter did not at the time have the opportunity to investigate, on the spot, the causes of this failure, for which he was held responsible as advocate for the use of superheated-steam locomotives; for in 1906, which was such an eventful year for the whole country, other pressing duties prevented him from having the necessary spare time. There was but one thing which he could assert with confidence, and that

(1) The superheated-steam locomotives of the Moscow-Kiew-Woronesh Railway are all fitted with Schmidt piston valves with spring rings.

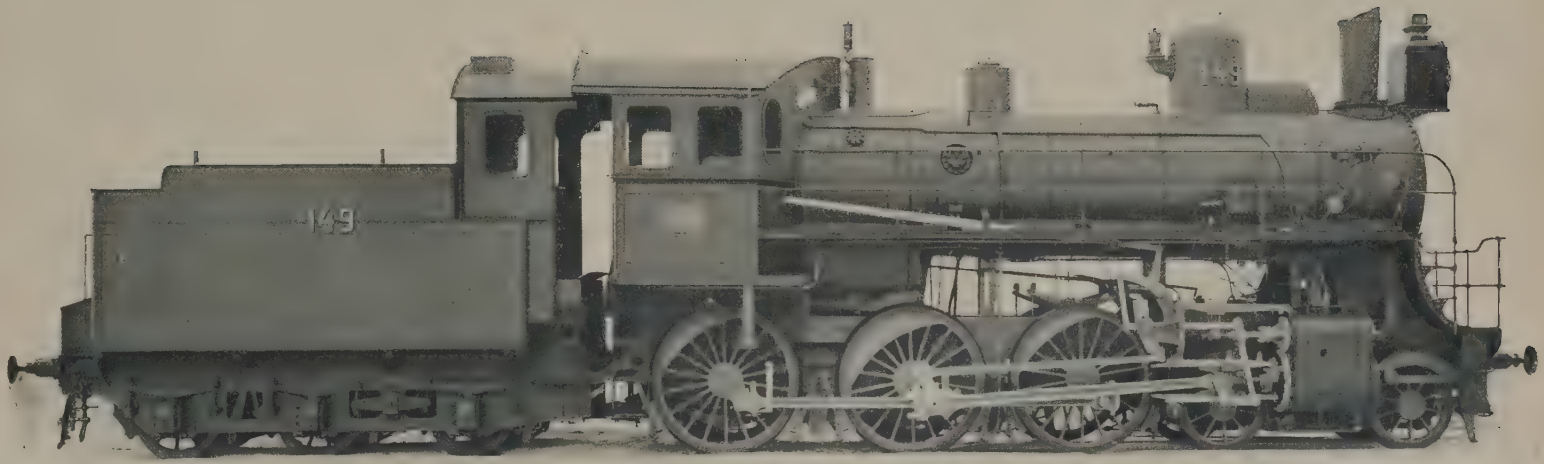


Fig. 8.

Fig. 9.

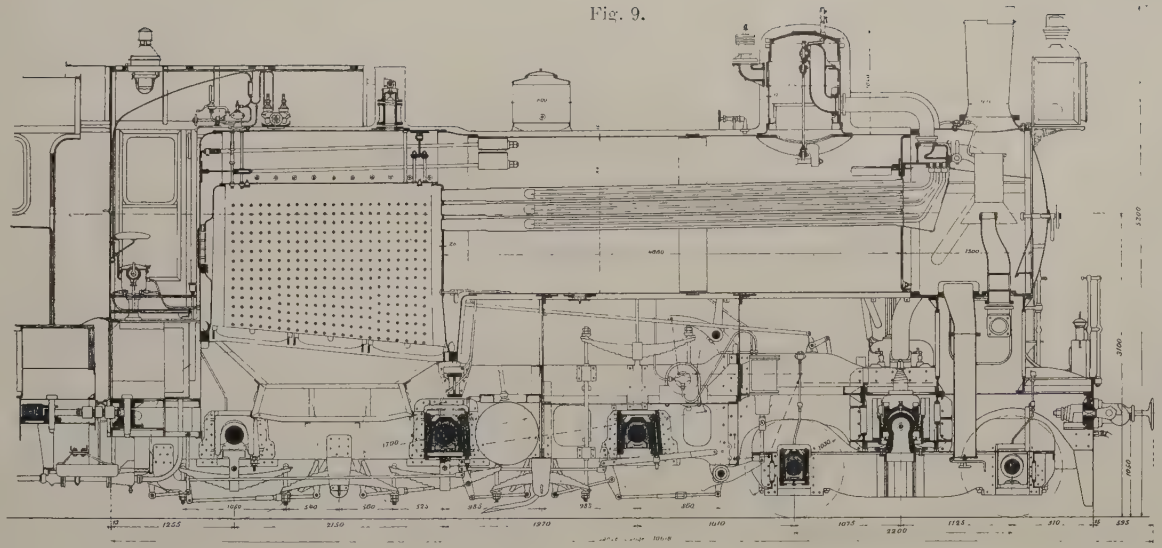
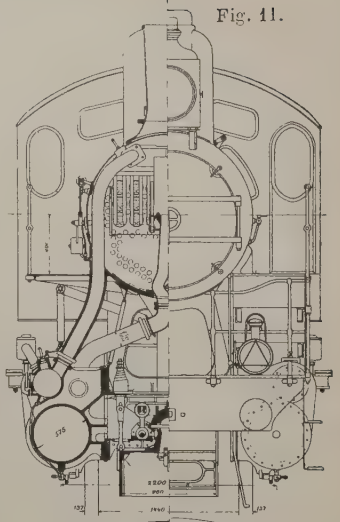


Fig. 11.



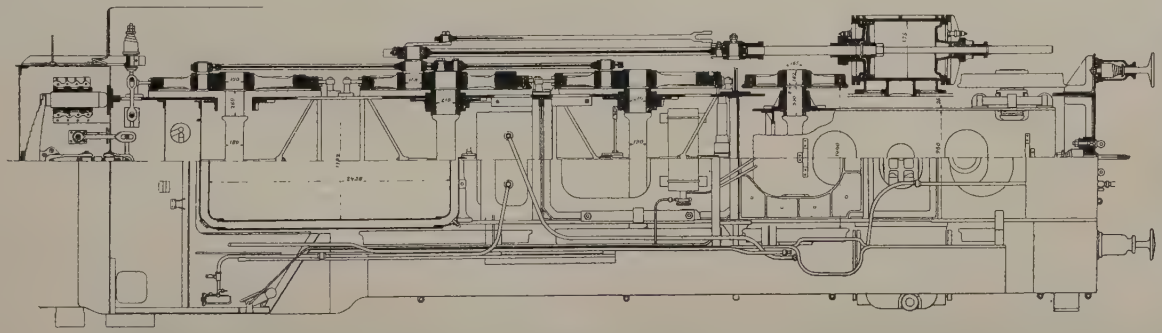


Fig. 10.

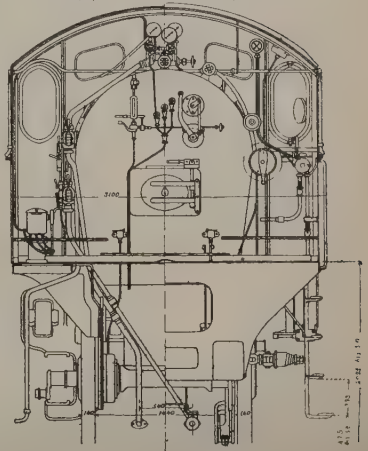


Fig. 12.

Figs. 9 to 12. — Moscow-Kazan Railway. — Passenger locomotive using superheated steam.

was that it was certainly not the superheating principle which was of itself responsible for the unusually-high fuel consumption of those Mallet locomotives, and consequently, the bad results obtained with the Mallet locomotives, the reasons for which he undertook to investigate, were no reason against the building of new superheated-steam express locomotives.

Fortunately the reporter succeeded in having his opinion adopted, and the new express locomotive, type Б. k. of the Moscow-Kazan Railway, was then designed and built; a locomotive which can be described as a brillant success of the superheated-steam principle.

It can be shown that the superheated-steam locomotive, even when producing small amounts of power, does not work extravagantly; its economical superiority over the wet-steam locomotive mainly depends on the possibility of having reduced admissions (from 15 per cent) without large condensation losses, and at high powers, on the joint working of a very perfect engine and of a very excellent boiler. Accordingly, it now was a question of designing a locomotive capable of hauling the heaviest trains (weight of wagons 500 tons [492 English tons]) at speeds of 35 kilometres (21·7 miles) per hour, even in winter under unfavourable conditions of weather, on the difficult undulating sections of the lines (gradients of up to 10 per mil combined with curves having a radius of 640 metres [32 chains], and up the gradients, without difficulty; and if necessary, also capable, without wasting fuel, of being used in the level country (lines with gradients of up to 6 per mil, and curves having a radius of 1,000 metres [50 chains]).

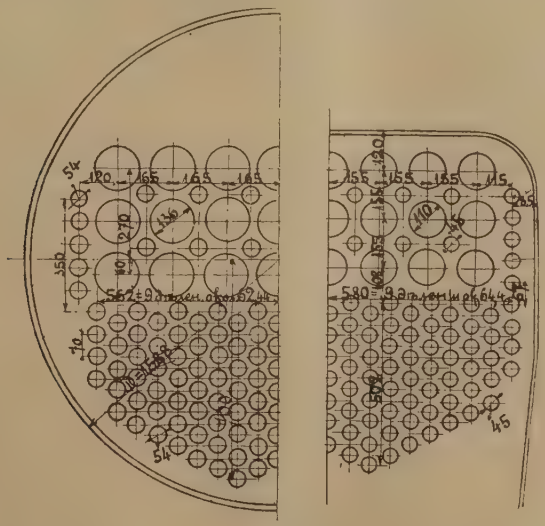


Fig. 13.

The following are the chief particulars of the locomotives designed to satisfy these requirements :

Superheated-steam passenger and express locomotive, type B. k.

(See figures 8 to 15.)

Diameter of cylinders	575 millimetres		(1 ft. 10 $^{5}/_{8}$ in.).
Length of stroke	650	—	(2 ft. 1 $^{5}/_{8}$ in.).
Diameter of driving wheels	1,700	—	(5 ft. 6 $^{15}/_{16}$ in.).
— of carrying wheels	1,030	—	(3 ft. 4 $^{9}/_{16}$ in.).
Smoke tubes, number	147		
— — external diameter	51	—	(2 inches).
— — length between tube-plates	4,660	—	(15 ft. 3 $^{1}/_{2}$ in.).
Heigth of centre line of boiler above rail-level	3,100	—	(10 ft. 2 in.).
Length of fire-box (at top)	2,321	—	(7 ft. 7 $^{5}/_{8}$ in.).
Width of fire-box (above grate)	1,192	—	(3 ft. 11 in.).
Heating surface of smoke tubes (external)	109·73 sq. metres		(1,181·15 sq. ft.).
— — of fire-box	13·63	—	(146·71 —).
— — of flue tubes (124/133 mill.) ($4^{7}/_{8}$/$5^{1}/_{4}$ in.)	40·89	—	(440·13 —).
— — in contact with water	164·27	—	(1,768·20 —).
— — of superheater	39·00	—	(420·76 —).
— — total	203·27	—	(2,188·01 —).
Grate area	2·76	—	(29·70 —).
Working pressure	12 kilograms per square centimetres (171 lb. per square inch.).		
Wheelbase	7,930 millimetres (26 feet).		
Weight, empty	66,600 kilograms (146,830 lb.).		
— in running order	73,900	—	(162,920 —).

Load on rails :

Bogie 13,200 + 13,300	26,500 kilograms		(58,420 lb.).
Leading coupled axle	15,800	—	(34,830 —).
Driving axle	16,000	—	(35,280 —).
Trailing coupled axle	15,600	—	(34,390 —).
Total adhesive weight	47,400	—	(104,500 —).

This powerful locomotive shows a remarkable resemblance to one designed by Garbe at the same time and described by him in his work (1), a $^{3}/_{5}$ express locomotives; the leading coupled axle also is not the leading axle of the locomotive. The tires of the wheels of this axle have no flanges, and are 20 millimetres ($^{13}/_{16}$ inch) wider than the others; the reporter introduced this peculiarity on all the $^{3}/_{5}$ locomotive of the railway already twelve years ago. The bogie truck has a lateral play of 25 millimetres (1 inch) on each side, and the whole arrangement of the axles

(1) *Die Dampflokomotiven der Gegenwart*, p. 448.

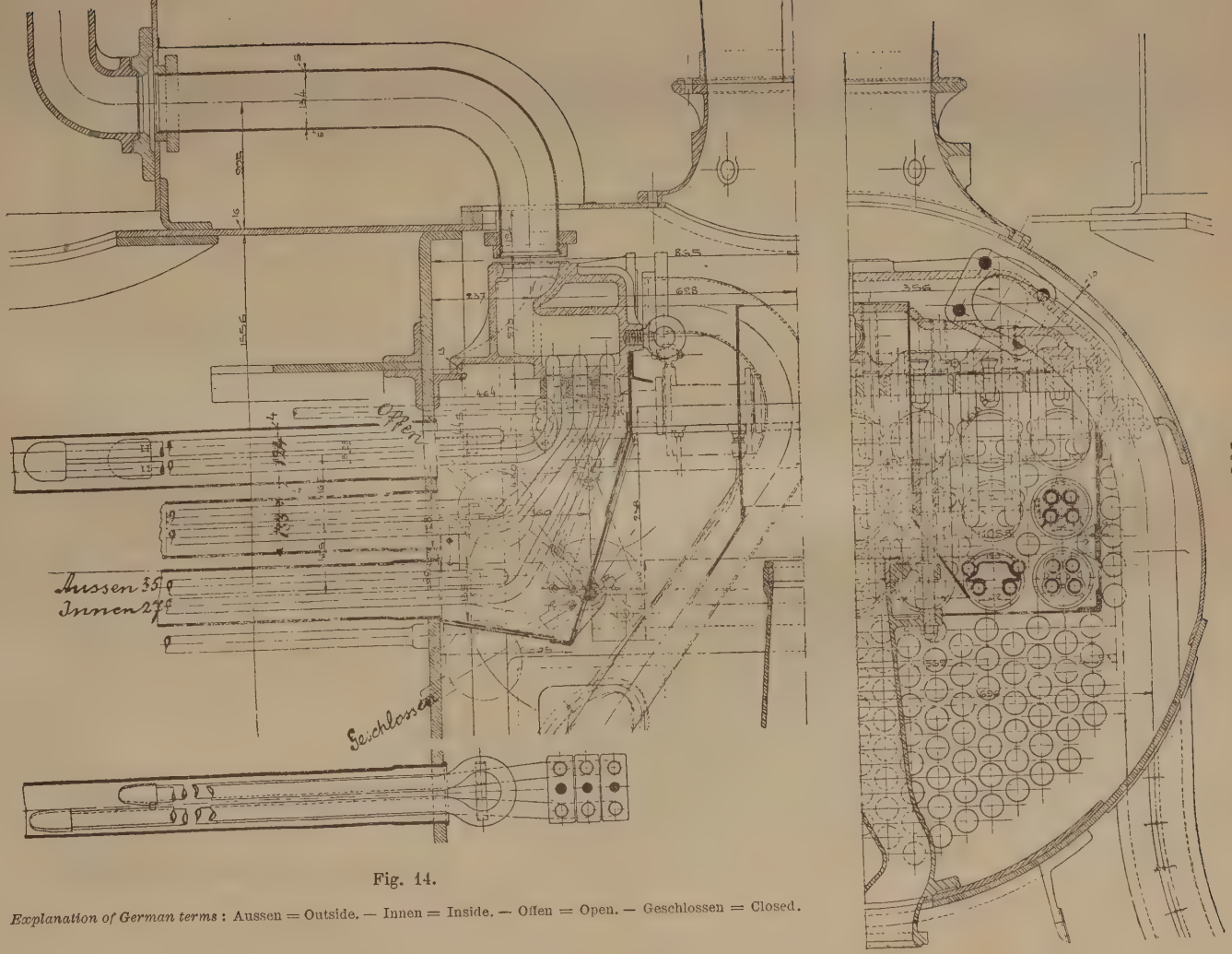


Fig. 14.

Explanation of German terms: Aussen = Outside. — Innen = Inside. — Offen = Open. — Geschlossen = Closed.

is such that only the wheels of the bogie trucks may have to come against the rails, an arrangement which has given satisfactory results in every respect.

During the earlier period after this locomotive had started running, difficulties arose in connection with the maintenance of the piston valves. The rings were made of unsuitable cast iron, became worn very quickly, were not tight and frequently broke. Consequently, these locomotives showed a comparatively-high steam consumption and fears were expressed that these locomotives would not satisfy expectations; the reporter, together with the chief engineer of the Kolomna Works, Mr. C. Gerstung, and the assistant locomotive inspector of the railway, Mr. P. Krassowsky, had put in much work on this design.

But matters changed suddenly after new rings had been fitted, at the works, to the piston valves; the locomotives, besides possessing great power, proved themselves economic and advantageous to the highest degree under the most varying conditions.

Used in competition with the 15,180-kilogram (33,470 lb.) lighter compound locomotive on the lines in the level country, the results given in the subjoined table were obtained, as regards fuel consumption; and these show the distinct superiority of these superheated-steam locomotives. It is to be noted that owing to the comparatively-small amount of power required, the steam was always throttled so that the pressure in the valve chest amounted to 6 kilograms per square centimetre (85 lb. per square inch).

Table I.

Consumption of naphtha. Month of the year 1908.	Type Б. Г.		Type Б. k.		Fuel consumption of type Б. k. as compared with type Б. Г., per 10,000 wagon axle-versts, in percentages.	
	Per 100 locomotive-versts (per 100 locomotive-miles).	Per 10,000 wagon axle-versts (per 10,000 wagon axle miles).	Per 100 locomotive-versts (per 100 locomotive-miles).	Per 10,000 wagon axle-verst. (per 10,000 wagon axle-miles).		
	Poods (lb.).		Poods (lb.).		Plus.	Minus.
July	71·41 (3,891·16)	199·25 (10,885·64)	68·93 (3,755·48)	182·90 (9,964·86)	...	8
August	69·35 (3,778·37)	174·56 (9,510·47)	70·51 (3,841·56)	176·28 (9,604·18)	1	...
September	72·95 (3,974·50)	178·92 (9,748·00)	67·31 (3,667·21)	164·45 (8,959·66)	...	8
October	70·26 (3,827·93)	167·38 (9,119·28)	69·93 (3,809·98)	165·98 (9,043·00)	...	1
November	75·30 (4,102·54)	180·78 (9,849·34)	72·86 (3,909·60)	175·32 (9,551·88)	...	3
December	78·26 (4,263·80)	204·58 (11,146·03)	87·01 (4,740·71)	192·21 (10,472·07)	...	8

This shows that the opinion expressed by Mr. Garbe, that superheated steam can be used economically even with much throttling is well founded. Evidently there must however be a limit to this, and the reporter is of opinion that the figures in the table furnish an indication of where that limit is to be found, in the case of the conditions existing on the lines in the level country (trains weighing from 260 to 560 tons [256 to 551 English tons], and gradients and curves as mentioned above). It also depends on how economically the compound locomotive works, with which the comparison is being made; and in this respect the superheated-steam locomotives have no easy task before them in this comparison, as the Б. Г. compound locomotive is of a type which has been very carefully worked out, and is acknowledged to work economically.

Now as the fuel economies shown in the table are on the whole small, it appears a likely conclusion that under the conditions in question the throttling is approaching the limit at which the use of superheating still gives any economy as regards fuel consumption.

This seems to justify the opinion, that the diameter given to the cylinders, 575 millimetres (1 ft. 10 $^5/_8$ in.), is correct, and that larger cylinders (for instance, 590 millimetres [1 ft. 11 $^1/_4$ in.], on the new Prussian locomotives designed by Garbe), and consequently correspondingly more throttling would reduce to some extent the universality of the superheated-steam locomotive and consequently the advantage of its applicability on the lines in the level country.

Another factor, which limits the increase of the diameter of the cylinder to a certain extent, consists in the necessity of strengthening the driving mechanism, the axles and cranks; this results in an increase in the frictional work and a corresponding reduction in the mechanical efficiency and one would thus be compelled to approach American conditions to a serious extent.

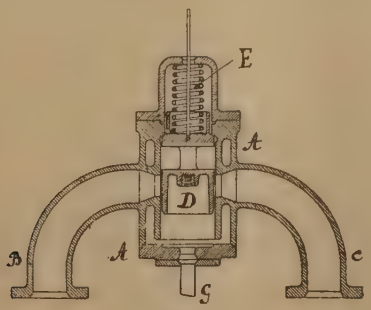
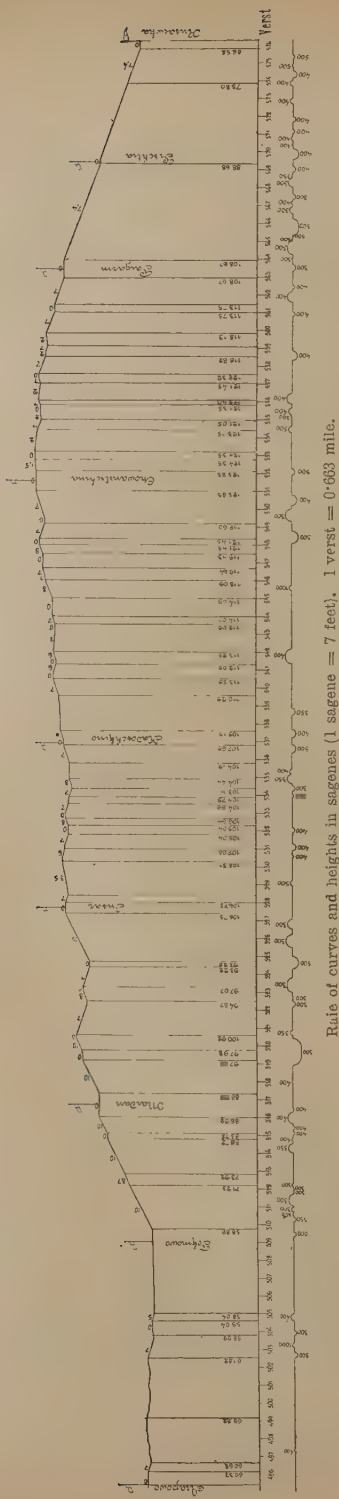


Fig. 15.

On the undulating sections the Б. k. type gives really brilliant results, particularly as since its introduction double heading has become quite unnecessary.

In order to compare the two types when producing moderate amounts of power,



Rule of curves and heights in sagenes (1 sagene = 7 feet). 1 verst = 0·663 mile.

Fig. 16. — Rusaewka-Arapowo experimental section.

and in order to test the behaviour of the superheated-steam locomotive after having been in service for a considerable period of time, trial runs were recently made which fully confirmed the eminent superiority of the superheated-steam locomotive, which is generally recognized and properly valued by the entire traction staff.

These trial runs were carried out under the supervision of Mr. Taube with booked trains on the Rusaewka-Arapowo line which is used by the reporter for all locomotive trials, and experience shows that very regular and comparable results are obtained there.

This experimental section is shown in figure 16; the trials runs are generally made in the Rusaewka direction. If the curve resistance on the Rusaewka-Paigarm section is converted into corresponding gradient according to the equation

$$i = \frac{650}{R - 60}$$

the corresponding average gradient of this section is 7 per mil, and that of the Paigarm-Chowanstschina section 3·27 per mil; the average gradient for the section Rusaewk-Chowanstschina then becomes 5·19 per mil.

The trials runs over the whole distance Rusaewka-Arapowo showed, for trains of medium weight (the train of the Б. k. locomotive weighed 285 tons [280·5 English tons], that of the Б. Г. locomotive 313 tons [308·0 English tons]), the following economies (referred to the unit of work, 1,000 pood-versts) (1) *in favour of the superheated-steam locomotive as compared with the wet-steam locomotive :*

Water, 24·75 per cent; fuel (naphtha), 16 per cent.

(1) 1,000 pood-versts = 17·48 ton-kilometres = 10·69 English ton-miles.

On the more difficult Rusaewka-Chowanstschina section, where the saturated-steam locomotive worked with increased cut-off (50 to 70 per cent, high-pressure cylinder), the condensation losses must have been less, *for here the water economy was only 15·3 per cent, while the coal economy was a little higher than for the whole distance, namely 16·5 per cent.*

These circumstances tend to show that part of the saving already results from the harder work of the saturated-steam boiler.

This surmise is confirmed by the temperatures observed in the smoke-box, which are given in table II. The figures in the table show not only that the temperature of the waste gases was considerably higher in the case of the wet-steam locomotive, than that of the gases coming out of the smoke tubes in the case of the superheated-steam locomotive, but also that it considerably exceeded that of the gases coming out of the superheater flue tube. The considerably higher vacuum in the smoke-box of the wet-steam locomotive also shows that much more is required of the boiler.

Table II.

Time of observation.	Wet-steam locomotive Б. Г. 129. Smoke box. Vacuum in millimetres (in inches) of water.	Wet-steam locomotive Б. Г. 129. Smoke box. Temperature, degrees C. (degrees Fahr.)	Superheated-steam locomotive Б. k. 146. Smoke box. Vacuum in millimetres (in inches) of water.	Superheated-steam locomotive Б. k. 146. Smoke box. Temperature of the gases coming out of the smoke tubes, degrees C. (degrees Fahr.)	Superheated-steam locomotive Б. k. 146. Smoke box. Temperature of the gases coming out of the superheater flue tubes, degrees C. (degrees Fahr.)	Superheated-steam locomotive Б. k. 146. Smoke box. Temperature of steam, degrees C. (degrees Fahr.)
Rusaewka, depart 7 h. 25. . .	...	...	...	...	...	...
— — 7 h. 30. . .	70 (2 3/4)	290 (554)	50 (2)	254 (489)	280 (536)	240 (464)
— — 7 h. 35. . .	80 (3 1/8)	372 (701·6)	60 (2 3/8)	305 (581)	320 (608)	280 (536)
— — 7 h. 40. . .	90 (3 9/16)	380 (716)	60 (2 3/8)	313 (595·4)	330 (626)	288 (550·4)
— — 7 h. 45. . .	80 (3 1/8)	375 (707)	40 (1 9/16)	284 (543)	290 (554)	285 (545)
— — 7 h. 50. . .	70 (2 3/4)	312 (593·6)	50 (2)	282 (539·6)	290 (554)	290 (554)
— — 7 h. 55. . .	80 (3 1/8)	310 (590)	60 (2 3/8)	317 (602·6)	320 (608)	300 (572)
— — 8 h. 00. . .	80 (3 1/8)	380 (716)	50 (2)	270 (518)	280 (536)	280 (536)
— — 8 h. 05. . .	90 (3 9/16)	380 (716)	40 (1 9/16)	303 (577·4)	310 (590)	300 (572)
— — 8 h. 10. . .	100 (3 15/16)	380 (716)	50 (2)	305 (581)	310 (590)	298 (568·4)
— — 8 h. 15. . .	90 (3 9/16)	380 (716)	50 (2)	280 (536)	290 (554)	290 (554)
Chowanstschina, arrive . . .	...	...	...	...	...	...

Remarks. — Locomotive Б. Г. 129 hauled train No. 9 from 10 September 1909; locomotive Б. k. 146 hauled the same train 9 September 1909.

It will be seen that the superheat leaves something to be desired, but with increasing power it rises to 300 to 320° C. (572 to 608° Fahr.).

As the load increases, the superiority of the supeheated-steam locomotive naturally becomes more evident up to its maximum load while the wet-steam locomotive has already reached its limit with a train of 360 tons (354·3 English tons).

The statistics of the locomotive department show that the whole traffic on the undulating section Riazan-Rusaewka has been transformed by the introduction of the Б. k. superheated-steam locomotive.

When wet-steam locomotives were used, the fuel consumption per unit of work exceeded that on the level section Moscow-Riazan by 30 per cent on the average; delays and the need of double heading were of constant occurence. After the new locomotives had been introduced, the fuel consumption became the same as on the line in the level country, and the passenger trains are run with the greatest punctuality. The last point is due to the circumstance that it is easy to make up any time lost accidentally (at points where goods trains are crossed). The large fuel economy is partly (14 to 18 per cent) due to the much more economic working of the superheated-steam locomotive, partly to the entire elimination of double heading.

The tractive effort of the superheated-steam locomotive, calculated according to equation

$$Z = 0{\cdot}75p \times \frac{d^2 l}{D}$$ [1]

is 11,377 kilograms (25,081 lb.), while that of the wet-steam locomotive, according equation

$$Z = 0{\cdot}55p \times \frac{d_n^2 l}{2D}$$ [1]

is 6,205 kilograms..

Now if we compare the cost of the locomotives for the tractive effort obtained, we find the following figures : superheated-steam locomotive, cost 47,155 roubles (£5,069.3*s.*), or 4,145 roubles per 1,000 kilograms (£202.2*s.* per 1,000 lb.) of tractive effort; wet-steam locomotive, cost 41,785 roubles (£4,491.18*s.*), or 6,733 roubles per 1,000 kilograms (£328.6*s.* per 1,000 lb.) of tractive effort.

The maintenance of the Б. k. superheated-steam locomotives has as yet not proved more costly than that of the corresponding wet-steam locomotives, and there is no reason whatever for supposing that this can change in the future. For although we must admit that the superheater tubes will have to be renewed in course of time, yet their life, on the basis of the results obtained with the smoke-box superheater, can be estimated at least ten years. If we also take into consideration that the

---

[1] d = diameter of cylinder; d_n = diameter of low-pressure cylinder; p = pressure in boiler; l = length of stroke of piston; D = diameter of driving wheels. (See Garbe, *Die Dampflokomotiven der Gegenwart*, p. 25.)

superheated-steam boiler has sixty-three smoke tubes fewer and evaporates at least 20 per cent of water less, which means corresponding reduction in the wear and tear of the boiler, it may ultimately happen that the balance will be in favour of the superheated-steam boiler.

The engine and the valve gear, if constructed and treated properly, will certainly cost less for upkeep than in the case of similar wet-steam locomotives with their clumsy flat slide valves.

The piston valves with internal admission and without stuffing-box packing for their rods require a hardly-appreciable amount of power to operate them and consequently there is much less wear in the links and link gear, than in the case of the wet-steam locomotives which are equipped with flat slide valves. The automatic forced lubrication which is indispensable on all superheated-steam locomotives also largely contributes to the better preservation of the rubbing surfaces in the cylinders and valve chests. As these lubricating arrangements distribute the oil very economically, the higher cost of the oil for the superheated-steam cylinders is hardly of any importance.

b) *0-4-0 goods locomotive*, A. II.

In the summer of 1909, twenty heavy superheated-steam locomotives were also put in service [1] as well as the 2-3-0 superheated-steam passenger locomotives just described. The chief particulars are given below.

Superheated-steam goods locomotive A. II.

Diameter of cylinders	575 millimetres	(1 ft. 10 5/8 in.).
Length of stroke	650 —	(2 ft. 1 5/8 in.).
Diameter of driving wheels	1,220 —	(4 feet).
Smoke tubes, number	147	
— — external diameter	51 millimetres	(2 inches).
— — length between tube-plates	4,660 —	(15 ft. 3 3/8 in.).
Height of centre line of boiler above rail-level	2,860 —	(9 ft. 4 5/8 in.).
Length of fire-box (at top)	2,079 —	(6 ft. 9 7/8 in.).
Width — (above grate)	1,444 —	(4 ft. 8 7/8 in.).
Heating surface of smoke tubes (external)	109·73 sq. metres	(1,181·15 sq. feet).
— — of flue tubes (124/133 mill.) (4 7/8/5 1/4 in.)	40·89 —	(440·13 —).
— — of fire-box	12 96 —	(137·34 —).
— — in contact with water	163·38 —	(1,758·62 —).
— — of superheater	39·00 —	(419·79 —).
— — total	202·38 —	(2,178·41 —).
Grate area	3·03 —	(32·61 —).

[1] These locomotives have up to the present only been used on certain short sections, for certain bridges had to be strengthened before these locomotives could be used.

Working pressure	12 kilograms per square centimetre	(171 lb. per square feet).
Wheelbase	3,890 millimetres	(12 ft. 9 3/16 in.).
Weight empty	59,500 kilograms	(131,170 lb.).
— in running order	64,400 —	(141,980 —).
Load on rails :		
Leading coupled axle	15,750 kilograms	(34,720 lb.).
Second — —	16,000 —	(35,280 —).
Driving axle	16,400 —	(36,150 —).
Trailing coupled axle	16,250 —	(35,830 —).

The tractive effort of this locomotive, calculated according to equation

$$Z = 0{\cdot}75\,p \times \frac{d^2 l}{D}$$

is 15,884 kilograms (35,018 lb.), which can be fully utilized with a coefficient of adhesion of 1/4·06. This locomotive costs 40,754 roubles (£4,381.1*s*.), or 2,750 roubles per 1,000 kilograms (£134.2*s*. per 1,000 lb.) of tractive effort, as compared with 3,919 roubles (£190.18*s*. per 1,000 lb.) for the 0-4-0 saturated-steam locomotives of the same railway.

In the case of a passenger locomotive, it is of the highest importance that it should work economically within wide limits, as the loads are so exceedingly variable; on the other hand, owing to the existing conditions on the Moscow-Kazan Railway, the most important requirements of goods locomotives are high power and the possibility of utilizing the existing adhesive weight fully under all conditions, so as to make it possible to deal quickly with the large amount of traffic which is offered in years of rich harvests. As there usually are four to six moderate years between the years of rich harvests, it would be very uneconomical to double the lines of the company, and hence it becomes necessary to operate the traffic with as heavy locomotives as possible.

These locomotives, in order to facilitate operation, have the same cylinders, superheaters, smoke tubes, boiler fittings, etc., as the locomotives last described.

The fire-box was made a little wider, as there was room for it. The experience obtained shows that it is better to obtain the increased grate area necessary, not only by making the grate longer but also by making it wider, and this is the reason why the new 2-3-0 and 0-4-0 locomotives have the centre line of their boilers rather high. This naturally makes it necessary to provide for the proper stiffening of the frame below the fire-box.

As yet no definite opinions can be expressed about the working results obtained with these locomotives, for on the one hand they have not been examined accurately, from the point of view of their economy, and on the other the 2 × 0-3-0 Mallet locomotives hitherto used on the same sections have given such poor results that any comparison would be without value. It will only be possible to make com-

Fig. 17.

Section through smoke-box.

Front view.

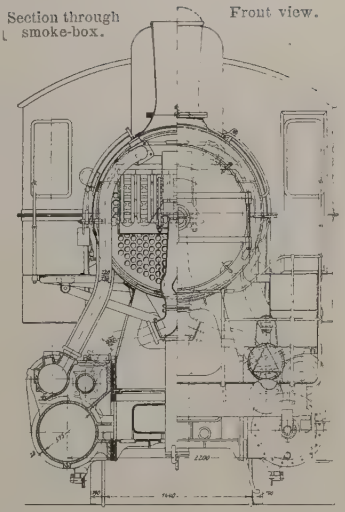
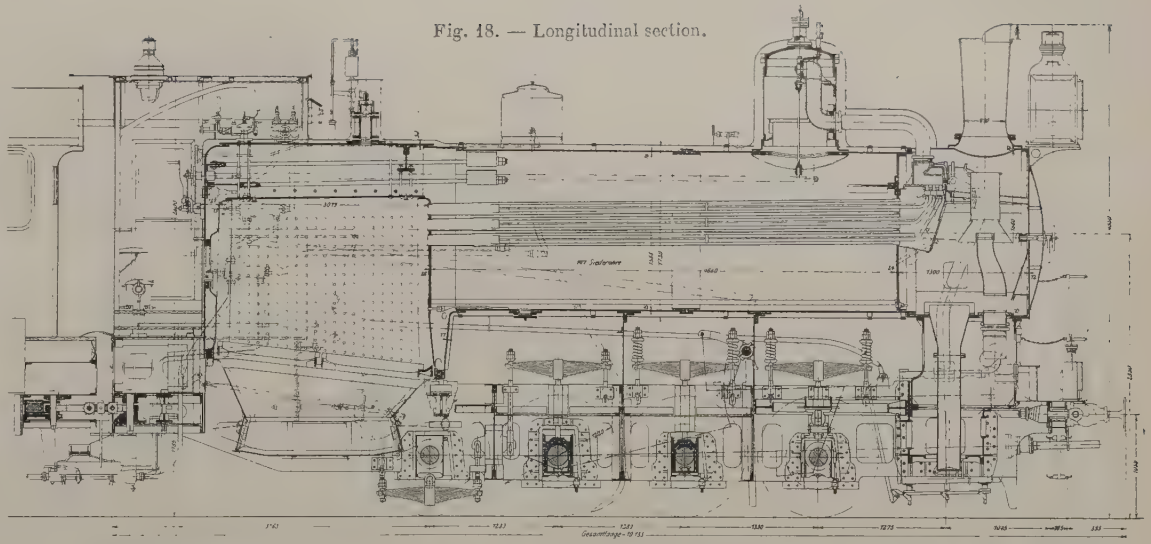


Fig. 18. — Longitudinal section.



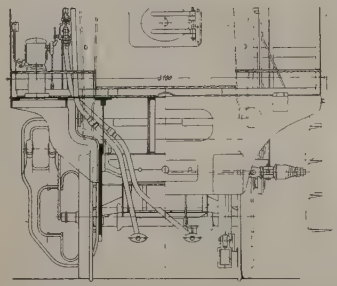


Fig. 20. — Section through *cab*.

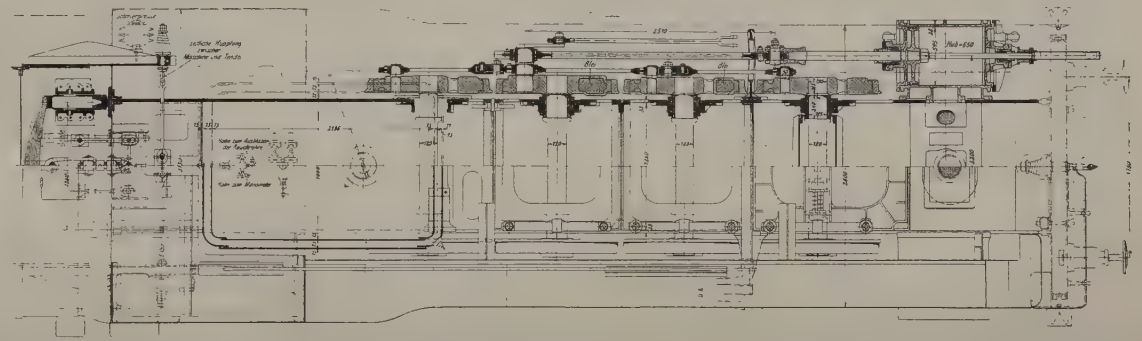


Fig. 19. — Plan.

Explanation of German terms : Schmierpresse = Plunger lubricator. — Seitliche Kuppelung zwischen Maschine und Tender = Lateral coupling between locomotive and tender. Hahen zum Ausblasen der Rauchröhren = Cock for blowing out smoke tubes. — Hahn zum Manometer = Cock to pressure gauge.

prehensive comparisons at a future time, when the alterations have been completed which will convert the Mallet locomotives into locomotives working economically. At present, it can only be established that this locomotive can haul trains of 975 tons (960 English tons) on the section shown in figure 16, and does not consume more water and coal than the much more complicated Mallet superheated-steam compounds after introduction of the improved piston valve.

As the latter are however capable of hauling trains weighing 1,250 tons (1,230 English tons), in spite of their complicated design, it cannot yet be decided which type is to be preferred in the given case (see section III).

The resulting steam temperatures vary, with a vacuum of 70 to 100 millimetres (2 3/4 to 3 15/16 inches), between 270 and 325° C. (between 518 and 616° Fahr), and it seems that these locomotives would give still better results if the superheater were larger. Accordingly with future locomotives of this type the boilers are to have twenty-four superheater smoke tubes, instead of twenty-one as at present. As regards the diameter of the cylinder (d = 575 [1 ft. 10 5/8 in.] for a driving-wheel diameter D = 1,220 [4 feet], which corresponds to d = 605 [1 ft. 11 13/16 in.] for D = 1,350 millimetres [4 ft. 5 1/8 in.] on the 0-4-0 Prussian goods locomotives), the present diameter is to be retained (1).

Finally, we have to mention one detail of the smoke-tube superheater which is not the same on the Moscow-Kazan Railway locomotives as on the usual Schmidt locomotives, and that is the collector in the smoke-box (see fig. 14). As the figure shows, the connexion with the regulator is effected by a tube above the boiler, which is protected against loss of heat by part of the boiler lagging. If this sheet-iron lagging is taken off, the bolts securing the tube flanges become readily accessible, and this is not the case with the usual design. This also enables the collector to be fixed better and more conveniently in the smoke-box. This arrangement of the collector has given good results. The railway is indebted for it to the chief engineer of the Putilow Works, Mr. Gololobow.

c) *Action of the Schmidt smoke-tube superheater and efficiency of the superheated-steam boiler.*

If we calculate, by means of the equation

$$L = \frac{m}{m-1}\, p_0\, v_0 \left(1 - \frac{1}{m} \times \frac{p^e}{p_0} \times \frac{v}{v_0} - \frac{m-1}{m} \times \frac{p}{p_0} \times \frac{v_0}{v}\right) \text{(2)}. \quad . \quad . \quad . \quad (7)$$

(1) The traffic service particularly values these locomotives owing to the quick rate at which they develop speed, and when leaving stations clear the block sections and release the signals.

(2) Here p_o = pressure at the beginning of expansion in kilograms per square metre;
v_o = volume at the beginning of expansion in cubic metres;
p_e = pressure at the end of expansion, in kilograms per square metre;
v = bak pressure, in kilograms per square metre; the influence of compression and of the clearance spaces being neglected.

the theoretical work L, given by 1 kilogram of saturated steam with an initial pressure of 10 and 13 kilograms per square centimetre, the cut-off being assumed to be 25 per cent, that is to say with a volume ratio of $\frac{v}{v_0} = 4$, and the steam being assumed to contain 3 per cent of water; then for

$$m = 1{\cdot}035 + 0{\cdot}1 \times 0{\cdot}97 = 1{\cdot}132,$$

we obtain

$$\frac{p_e}{p_0} = \left(\frac{v_0}{v}\right)^m = \left(\frac{1}{4}\right)^{1{\cdot}132} = 0{\cdot}1649;$$

and assuming a back pressure of 1·2 kilograms per square centimetre (17·14 lb. per square inch), or $p = 12{,}000$ kilograms per square metre, we have,

for 10 kilograms per square centimetre . . L = 34,568·71 kilogrammetres
— 13 — — — . . L = 37,272·91 —

Now as the heat required for generating 1 kilogram of saturated steam of the given pressure, the feed water being assumed to have a temperature of 20°, amounts, in the case of 10 kilograms per square centimetre, to

$$0{\cdot}97 \times 661{\cdot}1 + 0{\cdot}03 \times 181{\cdot}5 - 20 = 631{\cdot}56 \text{ heat units};$$

and in the case of 13 kilograms per square centimetre, to

$$0{\cdot}97 \times 668{\cdot}9 + 0{\cdot}03 \times 193{\cdot}7 - 20 = 634{\cdot}62 \text{ heat units};$$

it follows that the work produced per heat unit used, in the case of 10 kilograms per square centimetre, is

$$\frac{34{,}568}{631{\cdot}56} = 54{\cdot}73 \text{ kilogrammetres};$$

and, in the case of 13 kilograms per square centimetre, is

$$\frac{37{,}272{\cdot}91}{634{\cdot}64} = 58{\cdot}73 \text{ kilogrammetres}.$$

If we carry out the same calculations for steam superheated to 315°, assuming that the steam remains superheated till the expansion is completed, accordingly using the same equation (7), and taking the value of $m = 1{\cdot}3$ applying to superheated steam, then in the case of 10 kilograms per square centimetre we obtain

$$L_{\ddot{u}} = 43{,}167{\cdot}40 \text{ kilogrammetres};$$

and in the case of 13 kilograms per square centimetre we obtain

$$L_{\ddot{u}} = 45{,}224{\cdot}77 \text{ kilogrammetres}.$$

Now if we take the values of the mean specific heat $(c_p)_m$ of superheated steam found by Knoblauch and Jacob [1], and obtain by interpolation for our cases the corresponding values $(c_p)_m = 0{\cdot}528$ for a pressure of 10 kilograms per square centimetre and a temperature of 315°, and $(c_p)_m = 0{\cdot}541$ for a pressure of 13 kilograms per square centimetre and the same temperature, then we find by means of the equation

$$W' = \lambda + (c_p)_m (t' - t) - 20 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

that in order to produce 1 kilogram of superheated steam, the feed water being assumed to have a temperature of 20°, we require 717·96 heat units in the case of 10 kilograms per square centimetre and 716·96 heat units in that of 13 kilograms per square centimetre.

Accordingly, in the case of superheated steam, the work corresponding to 1 heat unit in the case of 10 kilograms per square centimetre is

$$\frac{43,167{\cdot}40}{717{\cdot}96} = 60{\cdot}52 \text{ kilogrammetres};$$

and in the case of 13 kilograms per square centimetre, is

$$\frac{45,224{\cdot}77}{716{\cdot}20} = 63{\cdot}14 \text{ kilogrammetres}.$$

If we compare these figures with those calculated for wet steam, we find that in order to obtain 1,000 kilogrammetres we have, in the case of 10 kilograms per square centimetres, to use

$$\frac{1,000}{54{\cdot}73} = 18{\cdot}27 \text{ heat units},$$

and in the case of 13 kilograms per square centimetre, to use

$$\frac{1,000}{58{\cdot}73} = 17{\cdot}03 \text{ heat units},$$

if we are using wet steam; while if we use superheated steam we require

$$\frac{1,000}{60{\cdot}12} = 16{\cdot}63 \text{ heat units}$$

and

$$\text{and } \frac{1,000}{63{\cdot}4} = 15{\cdot}84 \text{ heat units}$$

at these respective pressures.

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[1] See Schüle, *Wärmemechanik*, p. 150.

*

Hence it follows that if we use superheated steam, we effect under the given conditions economies of respectively

$$\frac{(18{\cdot}27 - 16{\cdot}63) \times 100}{18{\cdot}27} = 8{\cdot}98 \text{ per cent,}$$

$$\frac{(17{\cdot}03 - 15{\cdot}84) \times 100}{17{\cdot}03} = 6{\cdot}99 \text{ per cent,}$$

in the heat, and if the boilers are equally efficient, the same economies in fuel.

The water consumptions per 1,000 kilogrammetres are respectively

$$\frac{1{,}000}{34{,}568{\cdot}71} = 0{\cdot}0289 \text{ kilogram}$$

and

$$\frac{1{,}000}{37{,}272{\cdot}91} = 0{\cdot}0268 \text{ kilogram}$$

in the case of wet steam; and in the case of superheated steam they are respectively

$$\frac{1{,}000}{43{,}167{\cdot}40} = 0{\cdot}0232 \text{ kilogram}$$

and

$$\frac{1{,}000}{45{,}224{\cdot}77} = 0{\cdot}0221 \text{ kilogram.}$$

The water economies accordingly are respectively :

$$\frac{(289 - 232) \times 100}{289} = 19{\cdot}7 \text{ per cent,}$$

and

$$\frac{(268 - 221) \times 100}{268} = 17{\cdot}5 \text{ per cent.}$$

That the water economy and in particular the heat (fuel) economy become less at higher pressures is chiefly due to the fact that if steam is heated to a given temperature, the greater the pressure of the steam, the less the superheat, as the temperature of saturated steam increases with the pressure.

It is hence nearly useless to have greater pressures than 13 kilograms per square centimetre (185 lb. per square inch) when using superheated steam, all the more so as this is attended with an increase in the heat lost in the hot gases, and fewer heat units would pass through the heating surfaces. One of the greatest advantages of superheated-steam working is that its benefits are reaped without having to use any high pressures, exceeding 13 kilograms per square centimetre (185 lb. per square inch), and this is attended with a number of technical and economic advantages.

Fig. 21.

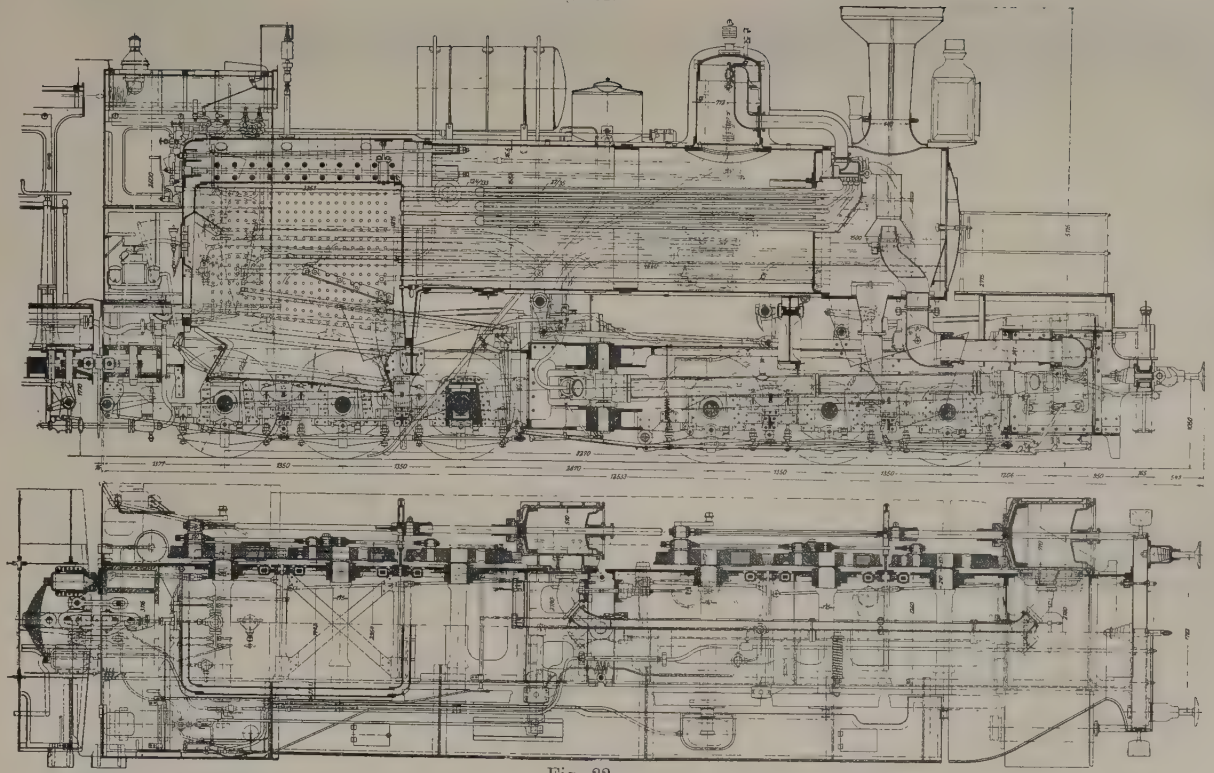

Fig. 22.

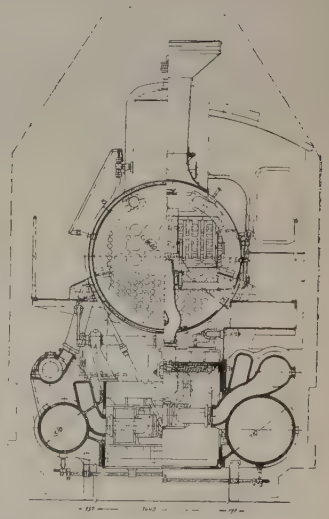

Fig. 23.

Diameter of high-pressure cylinder.	= 2 × 1 ft. 8 3/32 in.	Working pressure	= 171 lb. per sq. in.	Heating surface, total	= 2,305·63 square feet.
— of low-pressure cylinder .	= 2 × 2 ft. 3 15/16 in.	Heating surface of fire-box. . . .	= 159·84 square feet.	Grate area	= 37·67 — —
Length of stroke	= 2 ft. 1 5/8 in.	— — of tubes	= 1,726·0 — —	Weight, empty.	= 79·7 English tons.
Diameter of driving wheels. . . .	= 4 feet.	— — of superheater . .	= 419·79 — —	— in running order	= 87·5 — —

Figs. 21 to 23. — Moscow-Kazan Railway. Superheated steam four-cylinder compound 2×0-3-0 goods train locomotive, of Mallet type, with Schmidt smoke-tube superheater, built by the Kolomna works, and by the Putilow works at St. Petersburg.

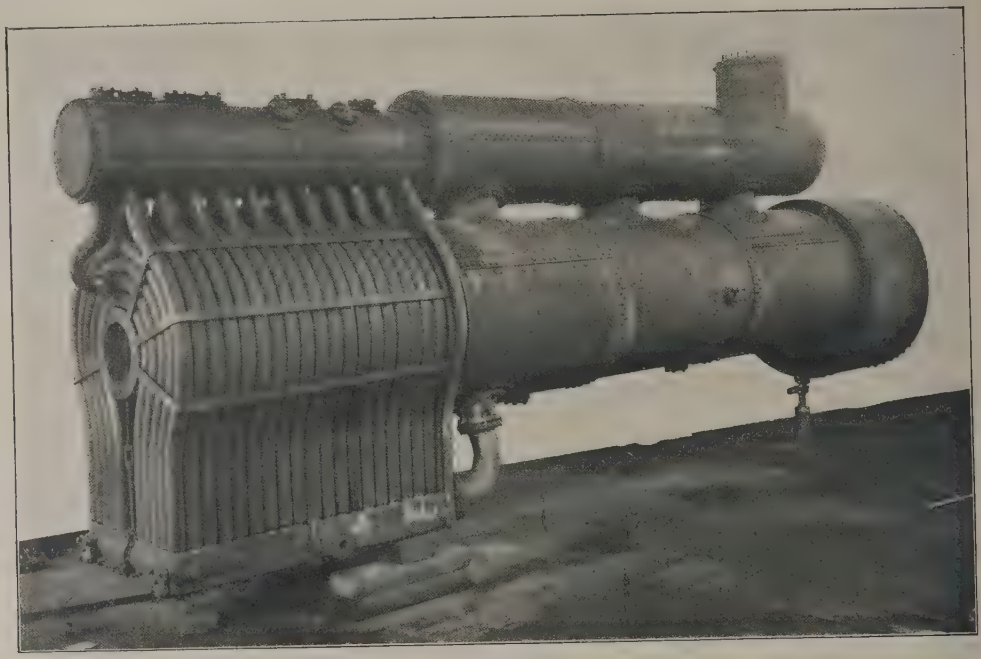

Fig. 24.

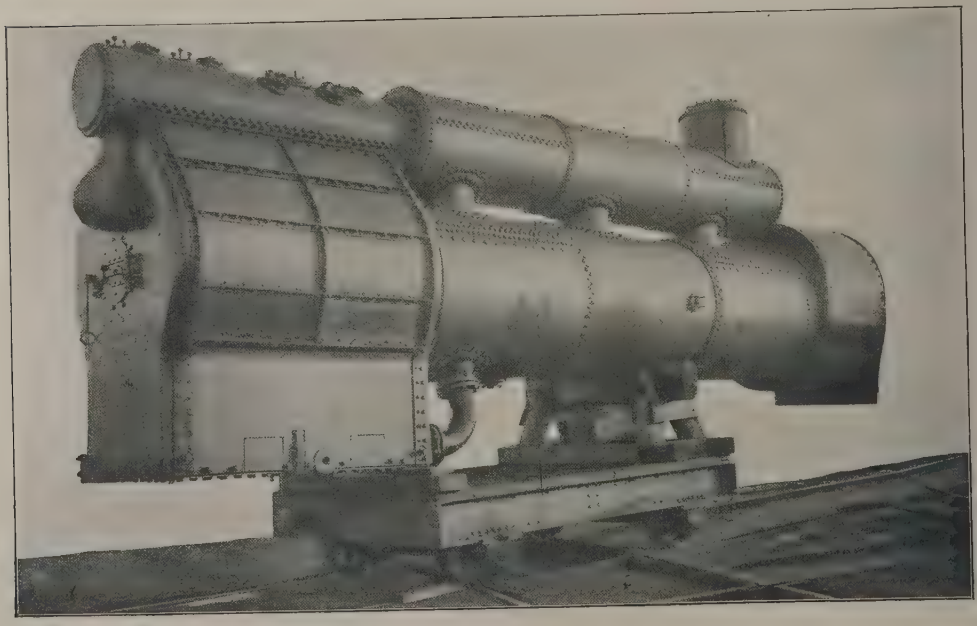

Fig. 25.

On the other hand with higher superheat, for instance up to a temperature of 350° C. (662° Fahr.), the pressure remaining the same, namely 13 kilograms per square centimetre (185 lb. per square inch), the heat economy as compared with wet steam would amount to 10·3 per cent and the water economy to 22·6 per cent.

Let us now more carefully consider the conditions, under which it would be possible to effect the economies calculated on the basis of the theoretical considerations given above. If we do so, we have to come to the conclusion, that these conditions are only satisfied to a very limited extent in the large majority of the superheated-steam locomotives constructed, including the types Б. k. and A. II. described above.

This depends in the first place on the insufficiency of the superheat, as shown in table II; we see that the temperature only rises to 300° C. (572° Fahr.) exceptionally, the average being about 280° C. (536° Fahr.). Now as the observed drop of temperature from the collector to the valve chest is at least 20° C. (36° Fahr.) on these locomotives, the temperature of the steam at admission can at most be 260° C. (500° Fahr.) If we calculate the work equivalent to 1 kilogram of steam superheated to this extent, by means of equation (7), under the same assumptions, we find

$$L_{\ddot{u}} = 40{,}651{\cdot}06 \text{ kilogrammetres,}$$

and, per heat unit,

$$\frac{40{,}651{\cdot}06}{687{\cdot}85} = 59{\cdot}09 \text{ kilogrammetres.}$$

In the case of saturated steam we obtained 58·73 kilogrammetres, and it follows that nearly the whole gain is lost.

Actually however several other losses also contribute. The steam does not expand adiabatically, but there is an exchange of heat with the cylinder walls. It is true that superheated steam is a very bad conductor of heat, but that is only the case if it is in a state of rest. We already saw in the case of the smoke-box superheater, that steam moving with great velocity greedily absorbs heat from the metal surfaces it flows over : and it can just as readily give up heat and become cooled. Now the superheated steam flows very quickly and forming many eddies through the small openings available with reduced cut-off and hence the large clearances spaces must have a considerable influence.

In addition we have assumed that the steam remains superheated until the expansion is completed; but this is not correct in our case. For after a certain amount of expansion the superheated steam reaches the dewpoint and then expands like saturated steam, and condensation takes place on the walls of the cylinder. The water so produced evaporates during the exhaust, taking heat from the cylinder walls, thus reducing the mean temperature of the latter.

Let p' be the pressure, v' being the corresponding volume, at which superheated steam, in the example we are taking (cut-off, 25 per cent), having an initial pressure

$p_0 = 130{,}000$ kilograms per square metre and an initial temperature of 315° C. (599° Fahr.), expanding adiabatically, becomes saturated steam, then as we know

$$\frac{p'}{p_0} = \left(\frac{v_0}{v'}\right)^{1\cdot3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

If 1 kilogram of dry saturated steam having the initial pressure p_0 expands to the limit curve of the critical state, then there must be a point on this curve which represents the saturation state $p'v'$, which the saturated steam reached when it expanded adiabatically. As the equation to the limit curve is expressed by

$$\frac{p'}{p_0} = \left(\frac{v_s}{v}\right)^{\frac{16}{15}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where v_s is the volume of 1 kilogram of dry saturated steam, it follows that

$$\frac{p'}{p_0} = \left(\frac{v_s}{v'}\right)^{\frac{16}{15}}$$

Combining this equation with equation (9) we obtain

$$\left(\frac{v_0}{v'}\right)^{1\cdot3} = \left(\frac{v'}{v_0}\right)^{\frac{16}{15}}$$

Working this out, we obtain :

for $p_0 = 10$ kilograms per square centimetre . . $\frac{v'}{v_0} = 3{\cdot}412$

and

for $p_0 = 13$ kilograms per square centimetre . . $\frac{v'}{v_0} = 3{\cdot}19.$

We accordingly see that the dew-point is attained before the steam has expanded to four times its initial volume; and that much earlier in the case of less-superheated steam of a higher pressure.

It follows from these considerations that the amount of superheat obtained with the locomotives hitherto described is much too low, and that *it can be stated, with a great degree of probability, that the work is not obtained which the better theoretical system could yield.*

If in spite of this, fuel economies of 16 to 20 per cent are actually observed, it is only due to a minor extent to the greater perfection of the system, and is chiefly due to the fact that in the case of superheated steam the condensation in the cylinders is either entirely avoided, or at least very much reduced.

When therefore the reporter described the two types of locomotives in question as a triumph of the superheated-steam principle, it should be added that by using more superheat much more success is still to be attained, as it would then be pos-

Fig. 26.

Fig. 26*a*.

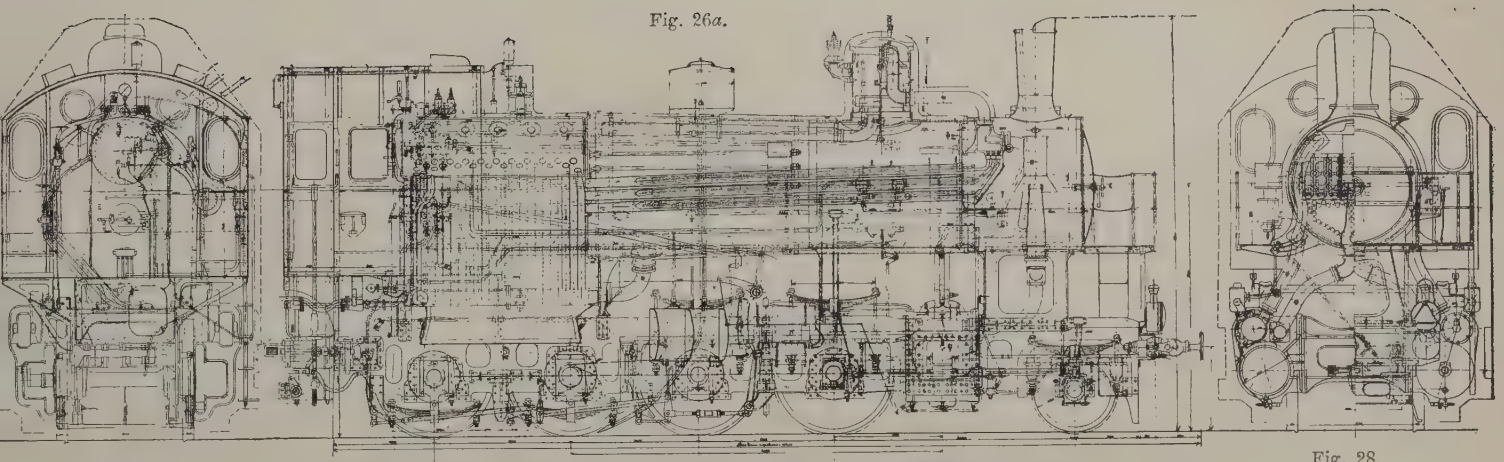

Fig. 28.

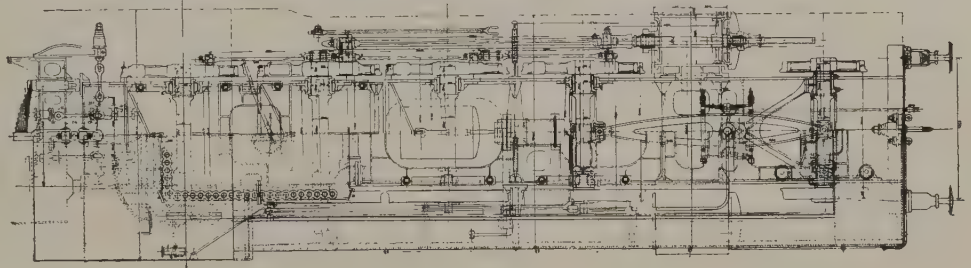

Fig. 27.

Figs. 26*a* to 28. — Chief particulars.

Diameter of cylinders *d*	=	575 millimetres	(1 ft. 10 5/8 in.).
Length of stroke *l*	=	650 —	(2 ft. 1 5/8 in.).
Diameter of driving wheels D	=	1,500 —	(4 ft. 11 in.).
— of carrying wheels	=	1,030 —	(3 ft. 4 9/16 in.).
Working pressure	=	12 atmospheres	(171 lb. per square inch).
Smoke tubes, number	=	132.	
Flue tubes, number	=	24.	
Diameter of smoke tubes	=	51/46 millimetres	(2/1 13/16 inches).
— of flue tubes	=	133/125 —	(5 1/4/4 15/16 —).
— of superheater tubes	=	29/36 —	(1 5/32/1 13/32 —).
Heating surface of fire-box H*d*	=	16·38 square metres	(176·31 square feet).
Heating surface of smoke tubes, external	=	98·28 sq. metres	(1,057 88 sq. feet).
— — of flue tubes	=	26·72 —	(287·61 —).
— — in contact with water	=	161·88 —	(1,742·47 —).
— — of superheater	=	47·20 —	(508·06 —).
— — total	=	209·08 —	(2,250·53 —).
Grate area	=	2·53 —	(27·23 —).
Weight, empty	=	62·8 tonnen	(61·80 English tons).
— in running order	=	69·63 —	(68·53 — —)
— adhesive	=	56·00 —	(55·11 — —).

Tractive effort $Z = 0{\cdot}5 \frac{p \cdot d^2 \cdot l}{D}$ . . . = 8,690 kilogramm (19,158 lb).

sible to gain a large part of the advantages made available by the improvement of the theoretical process.

The railway administration has accordingly determined to equip the fifteen superheated-steam passenger locomotives which are to be built during the current year, with twenty-four superheater smoke-tubes (figs. 26 to 28) each, in order to attain steam temperatures of 340 to 350° C. (640 to 662° Fahr.).

On the other hand, it has been contended that the locomotives do not always work with reduced cut-off and that if this were increased, it might happen that the exhaust steam would still be superheated, and this evidently would involve loss of heat.

This is however not the case. It is true that the cut-off, with which a locomotive works, depends on the load, the profile of the line, the velocity, etc., and that consequently every locomotive runs at times with different cut-offs, when naturally the fuel and water economy will be the greater, the more work the locomotive does with the cut-off in favourable position. But in any case, the advantage of the property inherent in the superheated-steam locomotive, of running economically with a reduced cut-off, must not be left unutilized and provision must accordingly be made for as high a degree of superheat as possible.

Even if the temperature of the superheated steam is raised to 350° C. (662° Fahr.), then with a cut-off of 25 per cent the saturated condition, calculated by the method described, is reached for the volume ratio

$$\frac{v'}{v_0} = 3{\cdot}92$$

that is to say before the end of the stroke, and this justifies our statement, that in all cases where locomotives work with reduced cut-off, the superheat must be as high as possible.

Among the many trial runs, which the reporter made with the superheated-steam locomotives on this line during the last two years, there has not been a single one on which there was any sign of too much superheat, and the attempt is shortly going to be made to send more heat to the superheaters, by contracting the cross-section of the openings of the clear smoke-tubes in the tube-plates of the B. k. and A. II. locomotives. All kinds of trials until now have on the contrary shown that the locomotive worked the more advantageously, the higher the superheat, and the reporter consequently thinks that it is unimportant if a small amount of heat passes away in the exhaust. This heat is not altogether lost as regards the efficiency, in so far as it heats the walls of the cylinders and clearance spaces and keeps them in such a condition that they do not reduce the action of the fresh entering steam so much as if strongly cooled, or still worse, wet steam had left the cylinder. These circumstances have the greater effect, the deeper the temperature variations extend into the metal of cylinders; hence especially at low speeds.

The idea of entirely preventing the cooling by the exhaust steam forms the basis

of the Stumpf valve gear, described in the next section, with which however an avoidable loss occurs, if the steam leaves the cylinder at too high a temperature.

The danger of an appreciable loss by having the exhaust steam still superheated in the case of increased admission in fact hardly exists. Let us for instance take the case of the 2 × 0-3-0 locomotives, types H. II., the boilers of which, according to the investigations described at the end of this section, generate 7,200·5 kilograms (15,874 lb.) of steam superheated to 315° C. (599° Fahr.) per hour, and let us assume a cut-off of 40 per cent.

In this case the final pressure determined by means of equation (9) is

$$p_e = 3{\cdot}95 \text{ kilograms per square centimetre,}$$

and the temperature at the end of expansion, determined approximately by means of the equation

$$\frac{v}{v_0} = \frac{p_0}{p} \times \frac{T}{T_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

is

$$t = 173{\cdot}9°.$$

If this steam were in the dry saturated condition, its temperature (corresponding to the pressure of 3·95 kilograms per square centimetre [56·18 lb. per square inch]) would be 142·3° (288·1° Fahr.), and would contain less heat to the full extent of the superheat.

In this case $(c_p)_m = 0{\cdot}508$, and the superheat $0{\cdot}508 \times (173{\cdot}9 - 142{\cdot}3) = 16{\cdot}053$ heat units; or for 7,200·5 kilograms, the whole steam supply for one hour, 115,590 heat units (458,661 British thermal units).

Now as the boiler, as the heat balance shows, utilizes 5,162,095 heat units per hour, the loss would be 2·24 per cent. But on the other hand, it is clear, that if the working steam is to be dry saturated steam at the end of the expansion, the temperature of the entering steam must be considerably less than 315° C. (599° Fahr.). It can easily determined (11) that it is approximately 273° C. (523° Fahr.), and the work given by 1 kilogram of steam becomes correspondingly lower. The difference per heat unit is about 5·19 per cent, as can be calculated by means of equation (7). The gain in work due to the greater superheat accordingly materially exceeds the heat lost. It must however of course be taken into consideration, that the production in the boiler of 1 kilogram of steam at 315° C. (599° Fahr.) requires more heat than if the temperature of the steam amounted to 273° C. (523° Fahr.). Let us assume for this case that with a medium amount of superheating the lowest attainable mean temperature of the waste gases in 242° C° (467·6° Fahr.), then we would get for the heating surface a ratio of

$$\frac{1{,}335 - 242}{1{,}335} = 0{\cdot}819 \text{ (}^1\text{).}$$

(1) Taking the temperature of the flames at 1,335° C. (2,435° Fahr.).

The case in which the boiler produces superheated steam at 315° C. (599° Fahr.), is carefully examined later on. The flame temperature being assumed to be 1,335° C. (2,435° Fahr.), the hot gases would in this case contain a total of 6,436,464 heat units, 1,239,774 of which would be lost in the waste gases. The ratio for the heating surface would then be

$$\frac{6,436,464 - 1,239,774}{6,436,464} = 0{\cdot}807.$$

The utilization of the heat in the boiler is accordingly only reduced by 1·46 per cent if steam of the higher degree of superheat is generated.

Taking all these circumstances into consideration, it appears that in spite of the loss due to superheat in the exhaust steam, there is an advantage in the higher degree of superheat.

The idea of preventing cooling by means of the exhaust steam forms the basis of the Stumpf valve gear described in the next section.

The reporter, continuing the consideration of the advantages of as high a degree of superheat as possible (up to 350° C. [662° Fahr.]), has to draw attention to the fact that according to be results obtained on the Moscou-Kazan Railway, so-called moderate superheating is undoubtedly disadvantageous as compared with high superheating, even in the case of compound locomotives.

The equipment for the moderate superheating costs as much and requires the same care and attention of the part of the employees, but it is of much less use.

The railway owns altogether thirty 2 × 0-3-0 Mallet locomotives with superheater, built in 1906 (see figs. 21 to 23), which are very nearly the same in all their details, except that the superheaters are of different sizes : twelve of the locomotives have 15 superheater tubes each, for moderate superheating, and the other eighteen have 21 superheater tubes each, for higher superheating. The heating surfaces, in square metres (in square feet), are as follows :

	Moderate.	*High.*
Fire-box	14·85 (155·53).	14·85 (155·53).
Smoke tubes	137·43 (1479·30) (184 tubes).	119·5 (1286·3) (160 tubes)
Flue tubes	27·81 (299·34) (15 tubes).	40·512 (436·07) (21 tubes).

Repeated trials made by the reporter on the experimental section (fig. 16) in the direction Rusaewka-Arapowo with booked goods trains show, that the locomotives with high superheat are in every respect superior to their sister locomotives with smaller superheater heating surfaces. They consume at *least 12 per cent less water than the locomotives with moderate superheat, and it is remarkable that their coal economy is even a little higher* (1).

The temperature of the steam varies between 240° to 260° C. (between 464 and 500° Fahr.) in the case of the locomotives with moderate superheat; in the case of

(1) Although of the same origin, the coal must accidentally have been better or mined very recently.

the others it was at first not much higher, about 270° to 285° C. (518° to 545° Fahr.). Only after the alterations which are described later on, was it possible to increase the superheat materially.

The object of the earlier trial runs made by the reporter on the sections shown in figure 16 was to ascertain the reason for the excessively-high coal consumption of the Mallet superheated-steam locomotives. The trial runs however proved so useful and so instructive in more than one respect, that they became a regular institution for testing the condition of the locomotives and the quality of the coal supplied to the railway, and are carried out at regular intervals on the basis of a scheme elaborated by the reporter.

Particular attention is devoted to determining the consumption of feed-water as accurately as possible, as this forms the chief basis in the estimation of the condition of the locomotives. At the Rusaewka locomotive sheds, carefully-graduated tenders are kept available, each with four water-gauges, so that the amount of water in the tanks can be determined with accuracy even if owing to bad condition of track the tender is not in a perfectly-level position. The overflow water from the injectors is collected, measured and allowed for, also the water used for wetting the coal.

The ratio of the amount of water consumed from Rusaewka to the stopping place Paigarm, expressed in Russian pounds, to one thousand part of the product of the weight of the train (locomotive and tender included) multiplied by the length in versts of the section Rusaewka-Paigarm gives a number which we denominate the *characteristic* number of the locomotive in question.

If possible, the characteristic number of two locomotives is obtained on one and the same day with two consecutive trains; these characteristic numbers form the best, perhaps the only safe means, from the practical point of view, for ascertaining the condition of the locomotives in question, as far as economy is concerned. No delicate instruments, no long series of observations, are necessary for determining this characteristic number, nor do the employees determining it require any special skill. It is a number which can be obtained readily in the course of the ordinary service with comparative accuracy, but which is of great value for the technical control.

Now that the characteristic number for different locomotives of the same class but belonging to different depots is determined on one and the same trial section, this serves as a measure for the amount of care with which the locomotives are treated, and the administration has an additional means for judging the economical working of the different locomotive depots. Many surprising peculiarities have been observed, more especially have great differences been found in the working of locomotives of one and the same class.

Above all it has been shown how important it is really to know the locomotives with which a new one is compared and only to rely upon trials which can be repeated as often as may be desired and always give the same results.

After it had been finally settled in this way that nothing important could be

attained with *moderate* superheating, even in the case of compound locomotives, and that the temperature of the steam was too low even in the case of the locomotives constructed for a higher degree of superheat (21 flue tubes), the reporter had an experimental locomotive equipped with a damper made of sheet iron, which turned about a horizontal axis in the smoke-box, in such a way that the draft through the smoke tubes could be reduced and a greater quantity of the hot gases sent through the flue tubes.

Experience showed that it was advantageous always to keep the damper in its extreme position, in which it most reduced the passage of the hot gases through the smoke tubes. The damper was therefore removed, and the clear cross-section of the tube ends in the fire-box tube-plate was reduced by driving rings made of flat bar 2 millimetres ($^3/_{32}$ inch) thick into half of the tubes. The reporter at the same time gave orders that when the boiler was cleaned out the scale adhering to the flue tubes should only be removed over a length of 800 millimetres (2 ft. 7 $^1/_2$ in.) from the back tube-plate, but that a thickness of 2 to 3 millimetres ($^3/_{32}$ to $^1/_8$ inch) should be kept left at the parts enclosing the superheater tubes, so as to prevent to some extent the transmission of heat to the boiler water and leave the hot gases more heat for acting on the superheater tubes.

As a result of these measures, the temperature of the steam rose to a maximum of 300° C. (572° Fahr.), and this proved a great advantage from the point of view of the economy of the locomotive. Then the clear cross-section of all the smoke tubes was reduced, with the result that the maximum temperature of the steam rose to 330° C. (626° Fahr.), and this again increased the economy in water and in coal.

These results were confirmed by repeated trial runs, and they enable the conclusion to be drawn that both in the case *of twin engines as well as of compounds, raising the temperature of the steam is an undoubted advantage as regards water and coal economy, as well as regards the efficiency of the locomotive.* Now as experience has shown that all the parts of a locomotive, with which steam comes into contact, can stand steam at 350° C. (662° Fahr.), it follows that this is the temperature which in actual working can not only be exceptionally attained, but should be kept up continually.

If cylinder oils were to be improved still further, the reporter feels sure that it would be a great advantage to go still further with the superheating in order to have steam at 350° C. (662° Fahr.) working in the cylinders. Not only will this result in still greater coal and water economies, but the boiler will also be subjected to less fatigue.

If as against this, it is asserted that even with the steam temperatures now usual the thermal efficiency of the superheated steam boiler is less than that of the old saturated-steam boiler, and that in this way some of the advantage is lost, we may observe that according to the results obtained on the Moscow-Kazan Railway this is not the case.

It is not easy to determine accurately how a boiler is working, as there are great

difficulties in making a locomotive work at a uniform rate, and in addition it is necessary to make a number of assumptions, not perhaps quite arbitrary, but at all events only approximate.

Nevertheless the reporter is of opinion that by fully utilizing observed results, even if obtained without exceptionally-delicate and costly systems of measurement, it is possible to obtain a rather deep insight into the action of a locomotive boiler; but it is necessary to complete the calculations in every direction and obtain a complete heat balance.

A trial made under the reporter's supervision will be discussed below, firstly in order to throw light on the efficiency of the boiler of the Mallet superheated-steam four-cylinder compound goods locomotive, and secondly in order to show how the thermal efficiency of the superheated steam and the action of the smoke-tube superheater can be investigated more closely.

The trial run took place 26 August-8 September 1909 with locomotive No. 864 and train 93. The locomotive weighed 86 tons (84·6 English tons), the average weight of the tender was 37 tons (36·4 English tons); the train consisted of 120 axles and weighed 1,105 tons (1,088 English tons).

The Rusaewka-Paigarm section (see fig. 16) is 13·35 versts (8·984 miles) long, which were covered in 63 minutes, including a stop of 9 minutes at Pischlia, which is a passing place. The regulator was closed during 4 minutes while running, and during 8 minutes the speed was so slow that the time for steaming can only be reckoned one half, so that the corrected time for the run is

$$63 - \left(9 + 4 + \frac{8}{2}\right) = 46 \text{ minutes.}$$

The amount of water consumed during the run was 5,520·39 kilograms (12,170 lb.) (1), which gives a rate of evaporation per hour of

$$\frac{5{,}520{\cdot}39 \times 60}{46} = 7{,}200{\cdot}5 \text{ kilograms.}$$

The mean working pressure during the run was 13·4 kilograms per square centimetre (190·6 lb. per square inch), and this was kept up during the whole time with only slight variation.

The amount of water contained in the steam going to the superheater was determined by means of the Carpenter calorimeter; it amounted to 2·7 per cent.

The same figure was obtained on numerous other trial runs of other locomotives of the same class, with only very minor variations (on the lower side). The extreme figures were 1·73 and 2·7 per cent, and it accordingly seems, in agreement with the

(1) The figures which are doubly underlined here and also further on are observed or calculated with absolute certainty from observations, and hence can be considered correct values, free from error.

results of stationary tests, that the former exaggerated opinions as to the water content of steam supplied by locomotive boilers were chiefly based on an ignorance of the real amount of the condensation water at admission; there was a tendency to explain its presence, in large quantities, in part by the assumption that the steam carried over much water.

The heat required for generating the steam having the observed pressure and water content amounts to

$$W = 0{\cdot}027 q_t + 0{\cdot}973\ \lambda_t - 20{\cdot}18 = \underline{\underline{636{\cdot}40}},$$

where 20·18 represents the feed-water heat.

Now as 7,200·5 kilograms of water are consumed per hour, this requires for its evaporation

$$636{\cdot}40 \times 7{,}200{\cdot}5 = \underline{\underline{4{,}582{,}398{\cdot}2}} = W_d \text{ heat units.}$$

Special trials have shown that the lagging of the boiler covering the surfaces in contact with water and steam radiates $34{,}595 = W_s$ heat units per hour on hot days when there is hardly any wind, and the trial day was such a day. This amount of heat passes from the steam and water through the boiler plate to the lagging, and must be supplied by the hot gases through the heating surface in contact with water.

If we add together the quantities of heat and W_d and W_s, we obtain the whole amount of heat W_h passing per hour through the heating surface in contact with water:

$$W_h = W_d + W_s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Now it is evident that the amount of heat W_s lost be external radiation is not determined with full accuracy, for it is impossible to place the locomotive during the trial for determining W_s under exactly the same conditions as regards radiation of the sun, currents of air, etc., as when actually running. On the other hand, the value of W_s is so small as compared with W_d, that any want of accuracy in its determination is of very subsidiary importance for the purposes of the whole investigation, and that we may accordingly also assume W_s as determined correctly. Then

$$W_h = W_d + W_s = 4{,}582{,}398{\cdot}2 + 34{,}595 = 4{,}616{,}993{\cdot}2 \sim \underline{\underline{4{,}616{,}993}} \text{ heat units}$$

is the total quantity of heat passing per hour through the *heating surface in contact with water*.

It is just as easy to determine the quantity of heat utilized in the superheater for drying and superheating the steam; the amount corresponding to each kilogram of steam is

$$0.027r + (C_p)m\ (t' - t_0).$$

At a pressure of 13·4 kilograms per square centimetre (190·6 lb. per square inch) the heat of evaporation is $r = 474{\cdot}18$ [1] and the temperature of the boiler water is

[1] See Schüle, *Wärmemechanik*, p. 356.

$t_0 = 191{\cdot}9°$ C. (377·4° Fahr.). As the observed mean temperature of the superheated steam was $t' = 315°$ C. (599° Fahr.), the superheat is accordingly $t' - t_0 = 123{\cdot}1°$ C. (221·6° Fahr.), and the mean specific heat of the superheated steam under these conditions is

$$(C_p)_m = 0{\cdot}55 \text{ heat unit } (^1).$$

The total quantity of heat W_u required for drying and superheating the wet steam coming from the boiler accordingly is

$$W_u = 7{,}200{\cdot}5\,(0{\cdot}027 \times 474{\cdot}18 + 0\,55 \times 123{\cdot}1) = 7{,}200{\cdot}5\,(12{\cdot}803 + 67{\cdot}705)$$
$$= 7{,}200{\cdot}5 \times 80{\cdot}508 = 579{,}697{\cdot}854 \sim 579{,}698 \text{ heat units.}$$

The figures in brackets show the very large influence of the water content of the steam. On all the trial runs was the observation made, that the superheat began to be reduced as soon as the water-level was more than 150 millimetres (5 $^{15}/_{16}$ inches) above the fire-box crown. This allows us to infer that this results in increasing the water content of the steam; and this must be carefully avoided in the case of superheated-steam locomotives.

It is very difficult to determine the coal consumption and only an approximate estimate can be made, although on the experimental runs the weight of coal used for firing for each verst was determined by means of a spring balance. The difficulty consists in estimating the quantity of fuel left on the grate on arrival at Paigarm and in putting the fire into the same state as at the moment of starting.

Special experiments have shown that lighting the fires and heating the boiler and boiler water to the temperature corresponding to a pressure of 10 kilograms per square centimetre (142·2 lb. per square inch) requires 573·3 kilograms (1,263·9 lb.) of coal, when the water has an initial temperature of 20° C. (68° Fahr.). Hence this amount was deducted from the amount of coal actually used.

The coal consumed for the run Rusaewka-Paigarm was accordingly taken to be 44 poods 12 pounds = 725·47 kilograms (1,599·37 lb.) (²), and this corresponds to a consumption, per hour, of

$$\frac{725{\cdot}47 \times 60}{46} = 946{\cdot}38 \text{ kilograms.}$$

As the grate area is 3·4 square metres, this gives a coal consumption, per square metre of grate, of

$$\frac{946{\cdot}38}{3{\cdot}4} = 278{\cdot}3 \text{ kilograms per hour.}$$

(¹) *Ibidem*, p. 150.

(²) The amount used for firing was 45 poods = (1661·12 lb.) 753·48 kilograms; 1·71 poods were deducted for the further journey; this corresponds to $^7/_{42}$ of the last basket weighed.

The quantity of heat W_e utilized per hour in the boiler is made up of the heat of evaporation W_d and the heat of superheating W_u, and accordingly is

$$W_e = W_d + W_u = 4{,}582{,}398 + 579{,}698 = 5{,}162{,}096 \text{ heat units.}$$

Consequently, the number of heat units utilized for each kilogram of coal used for firing is

$$\frac{5{,}162{,}096}{946{\cdot}38} = 5{,}454{\cdot}5 \text{ heat units.}$$

The coal used is strongly-caking small coal supplied by the Franco-Russian Company in the Donetz coal field, of very high calorific value, which calculated according to the *Verein* formula (1) amounts to 8,141 heat units (2). In consequence of its powdery nature this coal has to be wetted considerably, 20 kilograms (44·09 lb.) of water being added to 100 kilograms (220·4 lb.) of coal. This makes the coal have the following composition :

Carbon	67·08 per cent.
Hydrogen	5·00 —
Oxygen	3·33 —
Sulphur	1·25 —
Water	18·34 —
Ash	5·00 —
	100·00 per cent.

A Fischer-Orsat apparatus was used for determining the composition of the smoke gases. The most probable average composition, under steady conditions, is

Carbonic acid	11·75 per cent
Oxygen	7·36 —
Nitrogen	80·89 —
	100·00 per cent

in percentages of volume of the dry hot gases (the water thus being excluded), and this was taken as basis for the further calculations.

Consequently the theoretical amount of air required is :

$$L_o = \frac{1}{23{\cdot}56}\left(\frac{8}{3}\,C + 8\,H - O\right) = 9{\cdot}15 \text{ kilograms.}$$

(1) $\zeta = 81\,C + 290\left(H - \frac{O}{8}\right) + 25\,S - 6\,W.$

(2) The average composition of the coal is : Carbon, 80·5 per cent; hydrogen, 6·0 per cent; oxygen, 4·0 per cent; sulphur, 1·5 per cent; water, 2·0 per cent; ash, 6·0 per cent.

Assuming complete combustion, without formation of carbonic oxide, the excess of air is

$$\alpha = \frac{21}{CO_2} \times \frac{1 + \frac{CO_2}{100} \times 3 \frac{H - \frac{O}{8}}{C}}{1 + 3 \frac{H - \frac{O}{8}}{C}}$$

If $CO_2 = 11{\cdot}75$, then

$$\alpha = 1{\cdot}522.$$

The real amount of air required accordingly is :

$$L_b = 9{\cdot}15 \times 1{\cdot}522 = 13{\cdot}93 \text{ kilograms,}$$

and the weight of hot gases per kilogram of fuel is

$$G_b = L + 1 - 0{\cdot}01\ A = 13{\cdot}93 + 1 - 0{\cdot}05 = 14{\cdot}88 \text{ kilograms,}$$

where we have to assume, instead of the 946 kilograms of dry coal used, an hourly consumption B_h of fuel of

$$B_h = 946 \times \frac{120}{100} = 1{,}135 \text{ kilograms.}$$

Corresponding to the varying percentage constitution of the coal the calorific value of this accordingly becomes

$$\zeta = 6{,}652{\cdot}9 \sim 6{,}653 \text{ heat units,}$$

and the quantity of hot gases produced per hour

$$G_b \times B_h = 14{\cdot}88 \times 1{,}135 = 16{,}888{\cdot}8 \sim 16{,}889 \text{ kilograms.}$$

At a temperature of t^o, according to the equation 10 and 12 given in appendix II, the total heat in this mass of gas is

$$W' = C \times G_b \times B_h \times t + G_b \times B_h \times \delta \times t^2 = Mt + Nt^2 \quad . \quad . \quad . \quad . \quad (13)$$

or in our particular case

$$W' = 4{,}102{\cdot}344\,t + 0{\cdot}53856\,t^2\ (^1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

In the examination of locomotive boilers, a very important part is played by the correct determination of the heat absorbed by the so-called " direct " heating surface (*i. e.*, that of the fire-box). If it were possible to determine the temperature of combustion T_0 and the temperature T_r of the hot gases when entering the smoke

(1) The reporter reserves for himself the right of explaining later on why in the case here considered the coefficient in equation (14) has not been corrected for unburnt carbon; and how this equation can be used for determining the excess of air.

tubes and flue tubes, then we could determine the quantity of heat W_F passing through the fire-box walls to the water by means of equation 14 as

$$W_F = 4{,}102{\cdot}344\,(T_0 - \tfrac{3}{4}T_r) + 0{\cdot}53856\,(T_0^2 - T_r^2). \quad . \quad . \quad . \quad . \quad (15)$$

Unfortunately however, the reporter was unable to determine T_0 by observation, as the instruments designed for the purpose had not yet been supplied when the trial runs were made. All that he consequently could do was to calculate the probable temperature of combustion by the estimation of the losses occurring during combustion, in the following manner :

The quantity of heat produced by the combustion of the whole amount of coal used, 1,135 kilograms, is, as the figures show, assuming there are no losses :

$$B_h \times \zeta = 1{,}135 \times 6{,}653 = 7{,}551{,}155 \text{ heat units.}$$

If we add to this the heat contained in the fuel and in the air used for the combustion, which is found to be 82,262 heat units approximately, if we introduce in equation (14) the value $t = 20°$, we obtain the whole quantity of heat in the hot gases after the combustion :

$$7{,}551{,}155 + 82{,}262 = 7{,}633{,}417 \text{ heat units.}$$

The equation

$$4{,}102{\cdot}344\,T_0 + 0{\cdot}53856\,T_0^2 = 7{,}633{,}417$$

then shows that for the given air supply the theoretically possible temperature of combustion is 1,550° C. (2,822° Fahr.).

This temperature is however not attained in reality, as owing to losses during combustion this total quantity of heat is not obtained.

Thus after the trial run was finished, it was found that the ash-pan, the smoke-box and the grate contained residues, consisting of cinders, clinker, unburnt coal and coke, as follows :

$$108{\cdot}12 + 38{\cdot}50 + 74{\cdot}12 = 220{\cdot}74 \text{ kilograms}$$

and this represents 9·4 per cent of the coal used (2,320 kilograms [5,137 lb.]). If we add, as in the former trials, 4·7 per cent as spark and smoke losses, and 1·75 per cent for radiation through the grate and for the heat lost in the residues falling through the grate, we arrive at a total loss of 15·85 per cent (1).

Thus of the theoretically possible 7,551,155 heat units, there are only used for raising the temperature of the products of combustion

$$7{,}551{,}155 \times 0{\cdot}8415 = 6{,}354{,}202 \text{ heat units}$$

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(1) The possibility of utilizing the results of a large number of experimental runs for estimating such losses forms a special advantage of this method of always carrying out the trial runs on the same section and with trains of approximately the same weight.

which, added to the initial heat of the fuel and the air gives a total quantity of

$$6{,}354{,}202 + 82{,}262 = 6{,}436{,}464 \text{ heat units.}$$

The temperature of the combustion in the fire-box, calculated by means of equation

$$4{,}102{\cdot}344\ T_0 + 0{\cdot}53856\ T_0^2 = 6{,}436{,}464 \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

thus is

$$T_0 = 1{,}335^\circ \text{ C.}$$

Using the equation given in the first chapter, (1),

$$K = 54 + 0{\cdot}514\ (T_0 - t_0)\frac{R}{H_d}$$

we can then determine the coefficient of heat transmission K of the fire-box. In our case when $R = 3{\cdot}4$ and $H_d = 14$ (1),

$$\frac{R}{H_d} = 0{\cdot}243,$$

and consequently

$$K = 54 + 0{\cdot}514 \times (1{,}335 - 191{\cdot}9) \times 0.243 = 196.77 \sim 197.$$

Now the equation given in appendix II

$$(M + 2\ Nt_0) \log_e \frac{T_0 - t_0}{t - t_0} + 2\ N\ (T_0 - t) = K \times H_d \quad . \quad . \quad . \quad . \quad (17),$$

then enables us to calculate the temperature of the gases when entering the smoke and flue tubes.

By taking average values and then interpolating, we find, that when

$$M = 4{,}102{\cdot}344 \text{ and } N = 0{\cdot}53856 \quad . \quad . \quad . \quad . \quad . \quad . \quad [\text{see equation (14)}]$$

and

$$K \times H_d = 197 \times 14 = 2{,}758$$

the value $t = 877^\circ$ satisfies equation (17).

If we denote this value by T_r, we obtain for the heat left in the fire-box

$$4{,}102{\cdot}344\ (T_0 - T_r) + 0{\cdot}53856\ (T_0^2 - T_r^2) = W_F = 2{,}424{,}486{\cdot}6 \sim 2{,}424{,}487 \text{ heat units.}$$

We have now arrived at the interesting and important question of *the division of the smoke gases between the smoke tubes and the flue tubes.*

If the superheater is to work advantageously, this must receive a definite quantity of hot gases and consequently also a definite quantity of heat.

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(1) Without deduction of the tube holes, but assumed at 14 square metres (150·7 square feet) owing to the want of action of a strip, 150 millimetres (5 7/8 inches) wide, at the grate.

This must be at least large enough, in order to prevent any cooling of the superheated steam at the front end of the flue tubes, i. e. *the temperature of the gases leaving the flue tubes must be at least as high as that of the steam coming from the superheater.*

The experience obtained on the Moscow-Kazan Railway shows that it is not always easy to satisfy this condition; this is shown in the case we are considering by the adoption of means for reducing the clear cross-section of the smoke tubes, which was necessary in order to increase the flow of hot gases to the superheater.

It follows that if we retain the superheater dimensions shown in figure 21 (1) every precaution must be taken in order to reduce the resistance to the gases. It is especially advisable not to have the bend connectors too thick and the pipe hangers holding the ends of the tubes in the smoke-box too near the openings of the tubes.

At first the temperature of the hot gases leaving the flue tubes was not only lower, in the type of locomotive in question, than that of the superheated steam, but was also about 20° C. (36° Fahr.) lower than that of the gases leaving the smoke tubes (283° C. as against 303° C. [541° as against 577° Fahr.]). Only when scale had formed on the flue tubes and the smoke-tube openings had been reduced by putting in the rings, did this become reversed; thus during the trial run in question the temperature of the gases leaving the smoke tubes and entering the smoke-box averaged 262° C. (501·6° Fahr.) while that of the hot gases leaving the flue tubes averaged 318° C. (604° Fahr.).

This seems to justify the conclusion, that with superheaters of the dimensions shown in figures 14 and 21, it would be better to have smoke tubes having a diameter of 46/40 millimetres (1 13/16/1 9/16 inches), instead of 51/46 millimetres (2/1 13/16 inches).

Of the fifteen 1-4-0 passenger locomotives now being built for this railway, some are being fitted with such smaller smoke tubes, and moreover all these locomotives will have welded bends with strengthened pointed ends (see figure 29), which are manufactured by the Lauchhammer Works.

Fig. 29.

(1) Flue tubes 133/124 millimetres (5 1/4 in. / 4 7/8 in.), superheater tubes 35/27 millimetres (1 3/8 in. / 1 1/16 in.), clear cross-section for the gases in the flue tube $\Omega - 4\ \omega = 12{,}076 - 3{,}848 = 8{,}228$ square millimetres (13·14 square inches), where Ω = cross-section of flue tube, inside, ω = cross-section of superheater tubes, outside.

It would be erroneous to assume that the reduction of cross-section in the flue tubes is the only factor affecting the division of the gases between the flue and smoke tubes. An equally important factor is no doubt the friction of the gases at the flue-tube and smoke-tube surfaces, and the superheater will work the better, the greater the ratio of the clear cross-section $\Omega - 4\omega$ to the line forming the boundary of this cross-section. Let D_i = the internal diameter of a flue tube, and d_a = the external diameter of a superheater tube, then the superheater works the better, the greater the value

$$\frac{\frac{\pi D_i^2}{4} - \frac{4\,\pi d_a^2}{4}}{\pi D_i + 4\,\pi d_a} = \frac{1}{4}\,\frac{D_i^2 - 4\,d_a^2}{D_i + 4\,d_a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

The problem of the division of the smoke gases at the tube-plate can easily be solved by calculation, if observations are available as to the temperature of that part of them which leaves the smoke tubes, as in the case in question, where this, as already stated, averaged 262° C. (504° Fahr.).

If the total quantity of hot gases is so divided, that the fraction β passes through the flue tubes, while $1 - \beta$ passes through the smoke tubes, then, if the total heat of the total gases, before division, is taken as before at

$$W = Mt + Nt^2 = 4,102{\cdot}344\,t + 0{\cdot}53856\,t^2$$

then the heat contained in the gases passing through the smoke tubes will be

$$W'' = (1 - \beta)\,Mt + (1 - \beta)\,Nt^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

and the fall of temperature in the smoke tubes is given by the equation

$$(1 - \beta)\,(M + 2\,Nt_0)\log_e \frac{T_r - t_0}{t - t_0} + (1 - \beta) \times 2\,N\,(T_r - t) = kH_s \quad . \quad . \quad (19)$$

where H_s represents the heating surface of the smoke tubes, which in this case is the inner surface in contact with the hot gases, amounting to 107·75 square metres. Accordingly $kH_s = 5,818{\cdot}5$. As the observed temperature $t = 262°$, the value of $(1 - \beta)$ can easily be calculated from the given equation. As $M = 4,102{\cdot}344$, $N = 0{\cdot}53856$, $T_r = 877$, $t_0 = 191{\cdot}9$, we obtain :

$$\frac{T_r - t_0}{t - t_0} = \frac{685{\cdot}1}{70{\cdot}1} = 9{\cdot}77318, \text{ and } \log_e 9{\cdot}77318 = 2{\cdot}2796418$$

This gives $1 - \beta = 0{\cdot}5549$, and accordingly $\beta = 0{\cdot}4451$. We will take the values $1 - \beta = 0{\cdot}555$ and $\beta = 0{\cdot}445$ as sufficiently accurate.

That is accordingly the proportion in which the hot gases are divided. The ratio of the cross-section of the openings in the tube-plate of the smoke tubes to that of the flue tubes was originally $0{\cdot}201062 : 0{\cdot}168248 = 1{\cdot}195$; and after the reduction $0{\cdot}162161 : 0{\cdot}168248 = 0{\cdot}968$; while the gases are divided in the ratio $0{\cdot}555 : 0{\cdot}445 = 1{\cdot}247$.

This shows that the friction at the superheater tubes offers the gases a comparatively-large resistance and these chiefly pass through the smoke tubes; consequently, as already stated, it is advisable to increase the number of the flue tubes and in addition reduce the diameter of the smoke tubes.

The total quantity of heat of the gases in the flue tubes is accordingly

$$W' = 0{\cdot}445\,(4{,}102{\cdot}344\,t + 0{\cdot}53856\,t^2) = 1{,}825{\cdot}543\,t + 0{\cdot}23966\,t^2 \quad . \quad . \quad (20)$$

while that of the gases in the smoke tubes is

$$W'' = 0{\cdot}555\,(4{,}102{\cdot}344\,t + 0{\cdot}53856\,t^2) = 2{,}276{\cdot}801\,t + 0{\cdot}29890\,t^2 \quad . \quad . \quad (21)$$

As we know that the hot gases are cooled from 877° to 262° in the smoke tubes, the quantity of heat transmitted by the heating surface of the smoke tubes and to the water in the boiler is

$$W_r'' = 2{,}276{\cdot}801\,(877 - 262) + 0{\cdot}29890\,(\overline{877^2} - \overline{262^2}) = 1{,}609{,}607{\cdot}8$$
$$\sim 1{,}609{,}608 \text{ heat units} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

Now we know that the total quantity of heat required by the boiler for generating the steam containing 2·7 per cent of water, and for covering the radiation losses, is

$$W_h = W_d + W_s = 4{,}582{,}398 + 34{,}595 = 4{,}616{,}993 \text{ heat units} \quad . \quad . \quad (23)$$

which must be transmitted by the heating surface in contact with the water. These figures show, that the quantity of heat required for the radiation losses amounts to 0·75 per cent of the total quantity of heat transmitted through the heating surface in contact with water. If we consider that this value applies to a rather high hourly output of the boiler, then it seems to agree very well with the usual average value of 1·00 per cent.

As we have seen, of the 4,616,993 heat units, $W_F = 2{,}424{,}487$ heat units pass through the walls of the fire-box, while the smoke tubes absorb $W_r'' = 1{,}609{,}808$ heat units.

Consequently the flue tubes must transmit to the boiler water

$$W_r' = W_h - (W_F + W_r'') = 4{,}616{,}993 - (2{,}424{,}487 + 1{,}609{,}608) = 582{,}898 \text{ heat units.}$$

According to equation (20) the number of heat units passing with the hot gases at 877° into the flue tubes is

$$W' = (1{,}825{\cdot}543 \times 877) + (0{\cdot}23966 \times \overline{877^2}) = 1{,}785{,}331 \text{ heat units.}$$

Of these $W^u = 579{,}698$ are used for drying and superheating the steam, $W_r' = 582{,}898$ pass through to the water in the boiler through the heating surface in contact with water; and in the waste gases there are lost

$$W' - (W_u + W_r') = 1{,}785{,}331 - (579{,}698 + 582{,}898) = 622{,}735 \text{ heat units.} \quad (24)$$

The loss in the waste gases, as they leave the smoke tubes and enter the smoke-box, is determined in the same way; according to equation 21, the hot gases leaving

the fire-box at a temperature of $T_r = 877°$ and entering the tubes contain the following total quantity of heat

$$W'' = (2{,}276{\cdot}801 \times 877) + (0{\cdot}29890 \times \overline{877^2}) = 2{,}226{,}647 \text{ heat units.}$$

As the tubes absorb $W_r = 1{,}609{,}608$ heat units, the loss in the hot gases amounts to

$$W'' - W_r'' = 2{,}226{,}647 - 1{,}609{,}608 = 617{,}039 \text{ heat units} \quad . \quad . \quad . \quad (25)$$

The total losses in the hot gases accordingly amount to

$$W_v = 622{,}735 + 617{,}039 = 1{,}239{,}774 \text{ heat units.}$$

But this includes the 82,262 heat units originally contained in the fuel and the air used. If we refer the losses to the total quantity of heat, which the fuel could theoretically develop, we only have to consider the difference :

$$1{,}239{,}774 - 82{,}262 = 1{,}157{,}512 \text{ heat units.}$$

Thus we arrive at the following heat balance :

Theoretically-possible production of heat

$$\zeta \times B_h = 6{,}653 \times 1{,}135 = 7{,}551{,}155 \text{ heat units.}$$

1. Altogether 15·85 per cent of this is lost as heat contained in the ashes, radiation into the ash-pan, pieces of coal which have dropped through, cinders in the smoke-box, sparks, or 1,196,953 heat units (6,354,202 heat units being produced on the grate).

2. The loss through external radiation is 34,595 heat units.

3. The total losses in the hot gases amount to 1,157,512 heat units.

4. The quantity of heat utilized in the boiler for evaporating, drying and superheating the steam is

$$W_d + W_{\ddot{u}} = 4{,}582{,}398 + 579{,}698 = 5{,}162{,}096 \text{ heat units.}$$

These four items added together give 7,551,155 heat units.

The quality coefficient of the whole boiler is accordingly

$$\eta = \frac{5{,}162{,}096}{7{,}551{,}155} = 0{\cdot}684\ (^1).$$

For the whole run this value, referred to dry coal, is found to be 0·73, which may be considered as agreeing very well with the calculated value η, as the part of the run

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(1) If we however start with the calorific value of the dry coal, of which 946·38 kilograms were burnt, we obtain the lower quality coefficient

$$\eta_1 = \frac{5{,}162{,}096}{946{\cdot}38 \times 8{,}141} = \frac{5{,}162{,}096}{7{,}704{,}480} = 0{\cdot}67.$$

The boiler is however not to blame for the powdery nature of the coal used, and hence the method described above was adopted.

which served as basis for the calculation was that during which the boiler had most to do.

As a test for checking the correctness of the calculations, equations and assumptions made, we use the degree of agreement of the calculated temperature of the hot gases leaving the flue tubes with the temperature actually observed.

We have 622,735 heat units as the value of the hot-gas losses of the superheater gases.

Accordingly to equation (20) for the total heat in the flue tubes

$$W' = 1{,}825{\cdot}543\,t + 0{\cdot}23966\,t^2$$

the temperature corresponding to the quantity of 622,735 heat units is $t = 327°$.

The observed mean temperature of the gases is 318°, or only 9° less; this can be looked on as an excellent agreement, as all the errors would accumulate at this point.

The results checked in this way can now be used for certain other deductions and further investigations.

Comparison of the quality coefficient of the superheated-steam boiler with that of the wet-steam boiler.

In the first chapter, for purposes of comparison with the Brotan boiler, we carried out a calculation for the boiler of the Mallet wet-steam compound locomotive of this railway, which we based on the conditions observed during our trial run. As the dimensions of the fire-box are the same, then, given the same vacuum, the fire-box of the wet-steam boiler would absorb, just as in our instance, $W_F = 2{,}424{,}487$ heat units. The tubes in the saturated-steam boiler (see appendix II) received 2,756,295 heat units; these two items together give 5,180,782 heat units. Deducting 34,594 heat units, the quantity lost by external radiation, we find that the quantity of heat utilized in the boiler is 5,146,187 heat units; the quality coefficient is accordingly

$$\eta = \frac{5{,}146{,}187}{7{,}551{,}155} = 0{\cdot}681$$

as compared with 0·684 in the case of the superheated-steam boiler. Thus in this case the latter not only does not give less favourable, but even slightly better results, than the wet-steam boiler.

It has already been observed that the hot gases, in consequence of the resistance caused by the superheater tubes, are chiefly forced through the smoke tubes. For every given ratio of cross-section of flue tubes and smoke tubes in the tube-plate, the ratio of division of the smoke gases $\beta : (1-\beta)$ depends on the strength of the draft. The ratio of 0·445 : 0·555 found by us applied to the observed mean vacuum of 103 millimetres (4 $^1/_{16}$ inches) of water in the smoke-box and 57 millimetres (2 $^1/_4$ inches) in the fire-box. As the draft increases, the share taken by

the smoke tubes becomes less, as the increased contraction of the gas current at the tube openings has a greater effect at the narrow smoke tubes than at the wider flue tubes. This results in a peculiar regulation of the quality coefficient, for the quantity of gas in the superheater increases with β and with it the temperature of the steam, but at the same time the heat lost in the waste gases from the superheater also increases; on the other hand the quantity of gas in the smoke tubes and consequently its end temperatnre is also less, so that less heat is lost in the waste gases of the smoke tubes.

It is evident that this regulation only takes place within certain limits, for the reduction of the temperature of the hot gases at the end of the smoke tubes continually becomes less as the temperature falls.

In any case, the example worked out shows that the efficiency of superheated-steam boilers cannot differ much from that of wet-steam boilers. This thus forms a brilliant proof of the superiority of the superheated-steam boiler, as the steam it supplies has so much more valuable properties than saturated steam.

These conclusions naturally only apply to boilers having dimensions and working under conditions which do not materially differ from those of the boiler of the trial locomotive. Similar calculations will supply information of the quality coefficients under other conditions.

Action of the superheater.

We have seen that the total quantity of heat in the gas current passing through the flue tubes is given by equation (20) :

$$W' = 1{,}825{\cdot}543\,t + 0{\cdot}23966\,t^2$$

In the first place we have to examine the behaviour of this current of gas in that part of the flue tubes which is between the tube-plate and the bend connectors of the superheater tubes; the surface in contact with the hot gases has an area of 6·1743 square metres (66·462 square feet).

All the calculations made indicate that as the hot gases move at a high speed, and as these tubes have a considerably larger diameter than the smoke tubes, there is no equalization of temperature at each cross-section. On the contrary, the delivery of heat is effected in this case in the way, that the gas current corresponding to equation (20) appears to be divided into two equal portions, one a central one (1), which surrounds the longitudinal axis of the flue tube, and the other a peripheral one, along the walls of the flue tube. The inner current delivers no heat, while the outer one becomes so cooled at the walls of the flue tubes as if there had been

(1) For the sake of brevity, we here consider one gas current only, by which we mean to express the whole of the twenty-one similar currents in all the flue tubes.

complete equalization of temperature. Both currents are equal to each other as far as quantity of gas is concerned.

Naturally this assumption is only meant as a simple expression of a complicated action. That an axial current of gas can flow onwards without cooling is intelligible without further explanation. The temperature of the peripheral current will continually increase from the circumference towards the centre. The action may however for the sake of simplicity be assumed to take place as described, but it must be remembered that the ratio of the weights of the two currents, taking the real distribution of the temperature into consideration, is different from that which has for the sake of simplicity been assumed.

For the purposes of calculation, we accordingly consider the gas current (20) as divided into two parts:

$$W_1' = 912{\cdot}771\ t + 0{\cdot}11983\ t^2 \text{ and } W_2' = 912\ 771t + 0{\cdot}11983\ t^2 \quad . \quad . \quad (26)$$

The former starting with the temperature $T_r = 877°$ which obtains in the fire-box at the tube-plate flows to the superheater bend connectors without becoming cooled. The latter however becomes cooled according to the equation

$$(M + 2N\,t_0)\log_e \frac{T_r - t_0}{t - t_0} + 2N\,(T_r - t) = k \times H_f = 54 \times 6{\cdot}1743 = 333{\cdot}4143, \quad (27)$$

where $M = 912{\cdot}771$ and $N = 0{\cdot}11983$; from this we obtain $t = 699°$.

On striking the bend connectors the two currents again become mixed and here contain the sum of the quantities of heat

$$W_1' = (912{\cdot}771 \times 877) + (0{\cdot}11983 \times \overline{877}^2) \text{ and } W_2' = (912{\cdot}771 \times 699) + (0{\cdot}11983 \times \overline{699}^2)$$

that is

$$W_1' + W_2' = (912{\cdot}771 \times 1{,}576) + (0{\cdot}11983 \times 1{,}257{,}730) = 1{,}589{,}240{\cdot}88 \text{ heat units.}$$

When entering the flue tubes, the whole gas current contained 1,785,330 heat units, and accordingly the flue tubes have transmitted 1,785,330 — 1,589,241 = 196,089 heat units to the boiler water; as already stated, 0·75 per cent of this, or 1,471 heat units are lost as external radiation, while 196,089 — 1,471 = 194,618 are utilized for evaporation.

The heat content of the gas current passing through the flue tube, according to what has been stated, amounts to 1,589,241 heat units at the beginning of the superheater tubes. According to equation (22), the temperature corresponding to this is 788·8°~789°.

Of this amount of heat, the hot gases delivered 579,698 heat units to the steam flowing through the superheater tubes, and 582,898 — 196,089 = 386,809 heat units to the boiler water through the walls of the flue tubes.

As the initial and final temperatures of the gas current are known (the initial temperature has just been found to be 789° C. [1,452° Fahr.], and the final tempe-

rature is 327° C. [621° Fahr.]), we can investigate the action of the superheater from several points of view. For the sake of clearness, all these temperatures at the different points of the superheater are given in a diagram (see fig. 30). If we now make certain assumptions as regards the heat-transmission coefficients of the flue tube and the superheater tube, and estimate the temperatures existing in the bend connectors FG and KL, then we can check the accuracy of this estimate, by calculation, with any degree of approximation desired. In order to do this, all that is required is to divide the superheater into a given number of longitudinal elements (say twenty), and starting from one end, determine for each longitudinal element the exchange of heat effected, under the assumption that the temperature within one given element is everywhere the same. If the estimates made are accurate, then : 1° the temperature found for the bend HJ must be the same as that of the last element in the tubes GH and KJ; 2° the quantities of heat tranferred to the steam in the superheater tube must correspond to those established as regards the general distribution of the heat in the boiler.

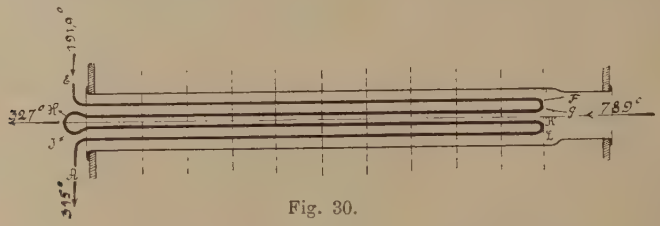


Fig. 30.

By successive trials, a satisfactory agreement is gradually arrived at.

In the case we are considering, as well as in the case of several other trial runs, these long and laborious calculations have been carried out with much skill by Mr. H. Taube, to whom the reporter is much indebted.

In the case we are considering, the heat-transmission coefficient of the flue tube was found to be 39, which may be considered as very probable, taking the amount of scale left into consideration. In the case of the heating surface of the superheater, several calculations have given the concordant results of $k_u = 65$ for the heat-transmission coefficient.

It is evident that the value of k_u is to some extent influenced by the assumptions made concerning the evaporation of the water contained in the boiler steam. The greater the number of the elements, over which the evaporation of the water is divided, the smaller the value of k_u, for the water necessarily has the same temperature as the boiler steam, and wherever a bubble of water strikes the wall of the superheater tube, there will be in consequence a greater drop of temperature. If this happens towards the end of the superheater tube, it is clear that the heat transmission will be increased most, for at the beginning of the tube, at E, this drop is present in any case, and if it is afterwards again brought about by the contact of

water, this is the more advantageous for the heat transmission, the smaller the drop existing in that part of the superheater where the particles of water strike, for at these places the existing drop is replaced by the original drop.

The above value of $k_u = 65$ applies to the case if the whole surface of the elements of the superheater tube is used *exclusively* for the evaporation of the water, as long as there is still any water in the steam. This is based on the assumption that the water carried over from the boiler is hurled against the walls at the bend of the superheater tube at E and is driven along these walls by the steam until it is evaporated.

Calculation shows that this requires $\frac{16}{20}$ of the length of the tube EF or $\frac{4}{20} = \frac{1}{5}$ of the length of a whole superheater tube; this, however, only applies if the level of the water is not more than 150 millimetres ($5\,^{15}/_{16}$ inches) higher than the fire-box crown. To have a higher level is inadmissible, for experience shows that the water content of the steam is increased and the temperature of the superheated steam is considerably reduced. The calculations are based on the assumption that the steam from the boiler contains 2·7 per cent of water.

Another limiting case for k_u arises, if we assume that the bend connectors FG and KL, in consequence of the short distance they are from the fire-box, are acted on by radiant heat; as may readily certainly occur, more particularly in the case of long-flaming coal. The heat which is in this way transmitted to the tubes and conducted along them, and transmitted to the steam, could materially reduce the value of k_u. On these assumptions the value becomes $k_u = 62$, which agrees with the value of k in the case of the smoke-box superheater.

The data in connection with these calculations are too extensive to be enumerated here, and the reporter proposes to give further particulars verbally.

In any case, the very numerous trial runs made on the experimental section shown in figure 16 show that twenty-one superheater flue tubes are not enough to keep up a sufficiently-high temperature in the steam, and consequently it is necessary to adopt further means in order to make a greater proportion of the hot gases pass through the flue tubes.

It accordingly seems more advisable to proceed inversely and use twenty-four flue tubes in order that a sufficient portion of the hot gases may in all cases enter the superheater, as provision is already made for reducing the superheat, if necessary, by means of the superheater damper. But that such a necessity should ever arise is very unlikely as far as present experience goes.

In order to give a comprehensive view of the whole heat distribution in the boiler examined, the reporter has given a summary of the results of these observations and calculations in table III, which requires no further explanation.

Finally, it may be mentioned that the velocity of the superheated steam when leaving the superheater was 26·52 metres (87 feet) per second in the case of the boiler examined. In the case of the locomotives designed for moderate superheat,

with only 15 flue tubes, this velocity is 37·13 metres (121 ft. 10 in.) per second; and in this the coefficient of heat transmission was found, exactly as in the other case, to be 65. From this we conclude that at the velocity of 26·52 metres (87 feet) per second the maximum value of the coefficient of heat transmission has already been attained and that there is consequently apparently no need for adopting any higher speeds. In reality however higher speeds are useful, as the superheater then works comparatively advantageously even when the locomotive does easy work.

Table III.

—	Calories. (British thermal units.)	Utilized. For evaporation.	Utilized. For drying and superheating in the superheater.	Lost by external radiation.	Lost in the waste gases.
		Calories (British thermal units.).			
Contained in the fuel and the air used	82,262 (326,416)				
Produced on the grade by the combustion.	6,354,202 (25,213,474)				
Total contained in the hot gases	6,436,264 (25,539,096)				
Transmitted to the boiler water by the fire-box.	2,424,487 (9,620,364)	2,406,303 (9,548,210)	...	18,187 (72,166)	...
Passed through the tube-plate	4,011,977 (15,919,524)				
Entered the flue tubes	1,785,331 (7,084,193)				
Before the superheater		194,618 (772,244)	...	1,471 (5,837)	...
At the superheater.		383,941 (1,523,478)	579,698 (2,300,242)	2,868 (11,380)	622,735 (2,471,012)
Entered the smoke tubes.	2,226,646 (8,835,331)	1,597,535 (6,339,019)	...	12,072 (47,902)	617,039 (2,448,411)
Total.		**4,582,397 (18,182,951)**	**579,698 (2,300,242)**	34,595 (137,285)	1,239,774 (4,919,423)
		5,162,095	(20,483,193)		
Deducting that left in the fuel and waste gases		...	...	...	82,262 (326,416)
				...	1,157,512 (4,593,007)
				1,192,107	(4,730,292)

It may be mentioned, for the sake of completeness, that the coal consumption of the locomotive examined, H. II. No. 864, for the whole trial section Rusaewka-

Arapowo (fig. 16), was 147·45 poods (5,324·61 lb.), including the 29·8 poods (1,076·11 lb.) used for lighting up, or, per unit of work (1,000 pood-versts of wagon weight), 1·08 Russian pounds (91·10 lb. per 1,000 English ton-miles).

Now if we do not include the 29·8 poods (1,076·11 lb.) used for lighting up in the coal consumption, we find this amounts, per unit of work, to 0·863 Russian pound (72·880 lb. per 1,000 English ton-miles).

The weight of the whole quantity of water evaporated on the trial section in the boiler was 926·02 poods (33,457·9 lb.). The water used on the Rusaewka-Paigarm part was 337·02 poods (12,170·25 lb.), so that the consumption per 1,000 pood-versts of train weight (allowing for the locomotive and tender) was 13·48 Russian pounds (1,136·97 lb. per English ton-miles) (see the " characteristic " number of the locomotive).

III. — Introduction of superheated steam on the 2 × 0-3-0 Mallet compound locomotives. Valve gear of superheated-steam locomotives.

a) *Introduction of superheated steam on the compounds.*

The desire to operate the traffic more simply and cheaply by increasing the train loads also on lines with weak superstructure, led to the use of the 2 × 0-3-0 Mallet locomotive on lines, for which lighter locomotives would apparently have sufficed; and it must be admitted that this type of locomotive has entirely satisfied expectations as regards not injuring the superstructure. For if we see a locomotive weighing 84 tons (82·6 English tons) in running order, hauling a goods train weighing 1,250 tons (1,230 English tons) on tracks laid with rails which only weigh 20 Russian pounds (8·19 lb.) per English foot, without in anyway affecting the safety of the superstructure or its maintenance, we must admit that it is really a triumph of locomotive design.

But as observed in section I, operation by heavy wet-steam locomotives has also its bad points, particularly if as in the case in question the loads go chiefly in the one direction (from east to west), and the heavy locomotives have to do the return journeys hauling trains consisting of empty wagons only, under which conditions these locomotives work very uneconomically.

For this reason, and because the long intermediate receiver which had a comparatively-small cross-section was much exposed to cooling, the reporter was fully justified in thinking that the introduction of superheated steam would be attended with great advantages in the case of these Mallet compound locomotives.

He was therefore considerably surprised when, on the contrary, complaints were made about the Mallet superheated-steam compound locomotives, shown in figures 21 and 22, soon after they had begun running; it was stated the consumption of fuel was disproportionately high. At first attempts were made to explain this by the unfavourable traffic conditions; but it was soon found that the Mallet superheated-steam locomotives consumed considerably more coal, for the same

amount of work, than the wet-steam locomotives of the same kind; a circumstance which largely contributed, in this country, to the extension of feeling against the use of superheated-steam for locomotive work.

The locomotives in question were built in part at the Putilow works at St. Petersburg, and in part at the Kolomna works. Both of these works were desirous of producing the better locomotive, and as according to the opinion existing at the time the chief problem, the solution of which was expected to result in much economy, consisted in obtaining low-pressure slide valves which were as tight as possible, each of these works claimed the option of being allowed to use its own special design for this important part of the engine, while adhering to the diameter specified by the railway.

The locomotives built by the Putilow works were equipped with very complicated valves of the Ricour type.

These consist of the piston head *a* (fig. 31), the piston disk *b*, and the piston ring *c*. The latter, as figure 31 shows, has a rib inside, by means of which the piston head and disk carry along the ring moving to and fro.

The ring, as shown in figure 31*c*, has two circular grooves turned in, to improve lubrication and tightness, and also has a ring lock of such dimension that when the ring is in place there is still a space of 15 millimetres ($^{19}/_{32}$ inch) between its ends.

The object of this arrangement is to make it possible to press together the ring still further and so allow for water, in the possible case of any collecting, and also to prevent damage to the cylinder or the motion.

At the place where the lock is, the hollow bronze body *e* is pressed from inside against the piston ring by the spring *f*, which takes against a projection on the disk *b*, and in this way makes it more difficult for the steam to pass through the lock.

The projection *h* at the side of the hollow body takes against the inside rib, mentioned above, of the piston ring.

In order that this rib may also in steam-tight contact with the piston disk *b*, it is elastically pressed against the disk by a special steel spring ring (1), which is clamped between the piston body and disk.

This also prevents any knocking of the piston ring and its life is improved. Besides the hollow body *e* there are also two cylindrical hollow bodies *i* (see fig. 31*k*) with springs *f*, which keep the piston ring in a central position.

The ring is a little smaller in diameter than the valve chest, so that when the regulator is closed the ring is not in contact with the chest, and there can be no friction. If steam enters between the two pistons, the pressure is transmitted through special holes O, O drilled through the disk into the inside of the piston, and this presses the ring against the liner.

---

(1) Shown in black in figure 31.

Care must be taken with this valve that the piston ring is only pressed by the spring angular ring against the piston disk, and is not fixed in. If the elastic force of the angular ring is overcome, the piston ring must have a play of about 0·5 millimetre ($^1/_{64}$ inch) in the direction of the valve rod.

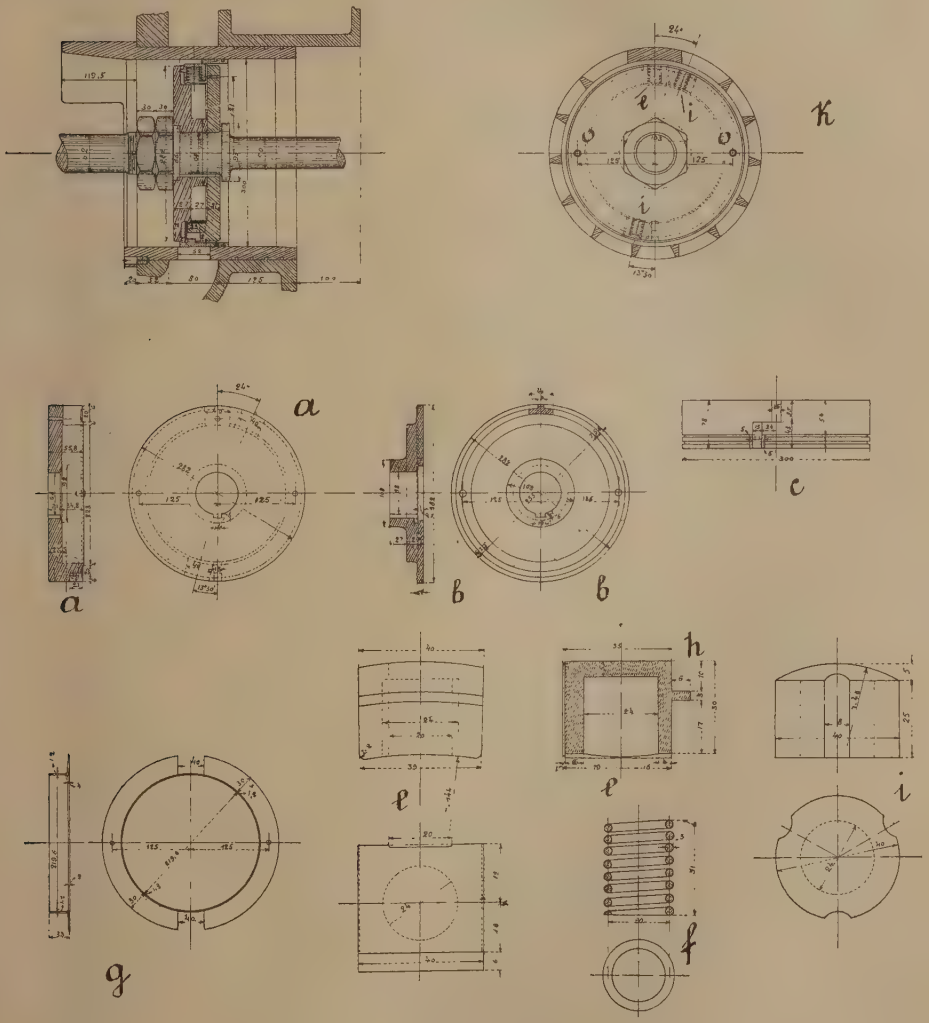


Fig. 31.

The piston rings of these valves are made of bronze on one half of these locomotives and of cast iron on the other half.

The latter have kept in better condition.

The locomotives built by the Kolomna works have low-pressure valves of the much simpler design shown in figure 32. The massive pistons, which are in two parts, carry the double rings shown on a larger scale in figure 32*a*, which are held by the piston at *b* and *c*.

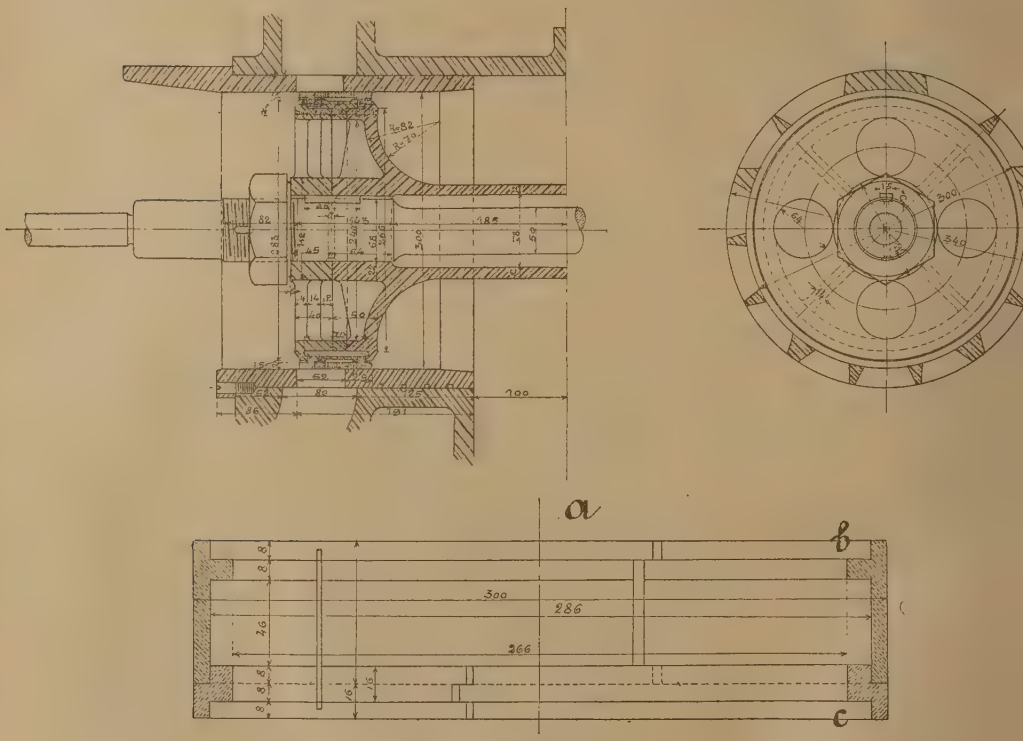


Fig. 32.

At first the rings were so placed relatively to each other, that the lock of the narrower ring formed a continuation of the lock of the wider ring, but afterwards the locks were displaced, by order of the locomotive department, as shown in figure 32*a*, as better tightness was then obtained.

In spite of all the attention devoted by the works to the design and the construction of the valves, all the Mallet superheated-steam locomotives, as already stated, proved to be extravagant in their coal consumption, using as they did 20 per cent

(and upwards) more fuel than the corresponding wet-steam locomotives. The heads of the locomotive depots explained this partly as a result of loss of steam in the low-pressure piston valves, partly also as showing that the advantages to be obtained by the use of superheated steam were of a problematical nature and certainly could not be realized in every case.

The Mallet superheated-steam locomotives were consequently used as little as possible, and when the goods traffic decreased they ceased running as soon as possible. This had been going on for two years, when one of the low-pressure cylinders on one of the locomotives became defective. Taking advantage of this circumstance, the administration decided to take out the two piston valves and replace them by flat valves.

The leading idea was still the same : the most important factor must be tightness in the low-pressure valves, for should the high-pressure valve leak, there would be no loss of steam, for this would still do useful work in the low-pressure cylinders.

Soon afterwards however, the locomotive H. H. No. 856, equipped with flat valves, was started running, and was tested on the experimental section shown in figure 16, which had been selected in the meantime. It was however found that the flat valves had not made the locomotive more economical at all, and that consequently the excessive consumption of fuel had nothing to do with the piston valves, which had been looked upon with so much mistrust.

In the mean time, the reporter had succeeded in making some progress in his theoretical investigations on the friction of railway rolling stock at curves, and this led him to examine more carefully the friction between wheel and rail at curves, as well as to determine the adhesion conditions of the Mallet locomotives.

To give a complete account of the results obtained in these investigations would take up far too much room in this report, and accordingly only the chief points are mentioned below.

On *straight* sections of line the tractive force is obtained by means of the *adhesion* between the tire and the rail. No slip takes place and the magnitude of the adhesive force coming into play in a given case varies between the limits 0 and fP, in accordance with the turning moment at the particular instant, where f represents the coefficient of friction when movement begins.

When running over a curve, the points of the wheel tires coming in succession into contact with the rails are compelled also to move in the direction at right angles to the rail heads, so that here, in the strict meaning of the words, there is no longer any *adhesion* coming into play, but only *sliding friction*, that is to say a force which is always opposing the slip of the point in of the tire, in contact with the time, on the rail head.

To find the direction of this slip, or, what comes to the same thing, to find the velocity of this movement, is consequently the first problem in the theory of this subject.

If the supporting point of a wheel only moves transversely to the rail, this wheel can naturally in no way contribute to the tractive force supplied by the locomotive, as the reaction (reaction of the rail) would be at right angles to the plane of the wheel. Consequently if the wheel which we are considering is to give part of the tractive force, the point of support on the rail head must also slip in a direction backwards. If this is the case, the resultant of the two movements is obliquely backwards, and the reaction of the rail is obliquely forwards, and so contributes towards the tractive force.

It follows that the greater the tractive force to be obtained from one point of support, the longer must the path be described on this rail by the point of support slipping backwards. If for instance the length of this backward slip is equal to that which the point of support describes transversely to the rail, then the resultant path ot the point of support, and at the same time the frictional resistance, will form an angle of about 45° with the centre line of the locomotive and the tractive force resulting from the friction fP of this point of support will be

$$\frac{f\mathrm{P}}{\sqrt{2}} = 0{\cdot}71\, f\mathrm{P}$$

where f is the coefficient offriction and P is the wheel-load.

If the tractive force is to be increased, the slip in the longitudinal direction must always increase; if we would desire to obtain the whole value fP as tractive force, then (assuming the coefficient not to change), it would be necessary that the sliding velocity of the point of support slipping in the longitudinal direction should be infinity. As the coefficient of friction f however decreases if the speed increases, it is quite impossible to obtain the tractive force fP on a curve.

We accordingly see that when running round a curve the locomotive wheels slip the more, the greater the tractive force required, and this slip may become very large if the amount of tractive force required from a given wheel approaches the value fP.

Now the result of this is that there is a certain difference between ordinary locomotives, which we will call " locomotives with undivided adhesion ", and the Mallet, Meyer, and other similar designs, which we will describe as " locomotives with divided adhesion ".

In the former case, for any given tractive force required, in consequence of the " principle of least action ", that minimum value of the angular velocity ω applies to all the coupled axles, at which the required tractive force is supplied, and the locomotive then works with a definite amount of slip of the points of support in the longitudinal direction of the rail, in other words " with a perfectly-definite quality coefficient of the adhesion ".

In the case of a locomotive with divided adhesion, the division of the tractive force between the two sets of wheels can take place in very different ways; in the case of the Mallet locomotive three axles can represent so large a fraction of the

tractive force, that this requires a very uneconomical and high angular velocity ω with a large amount of longitudinal slip friction; and in such a case, the locomotive would have to do considerably more work which would be uselessly expended in wearing away the tires.

On straight sections, particularly in the case of undivided adhesion, any slip of the wheels at once becomes apparent, for the adhesion fP is sensibly higher than the frictional resistance fP after slipping has begun. As a consequence, the wheels which have begun to slip at once turn with an increased angular velocity, and must at once be brought back to a state of " adhesion " by reducing the pressure in the valve chest (partly closing the regulators).

On a curve on the other hand, the wheels are continually slipping, and we therefore have to deal with the coefficient of friction f, whose value does not suddenly alter. Hence there may be an unnecessarily-large amount of slip and consequent friction, without any special phenomena in the behaviour of the locomotive; it is even possible to obtain quite good indicator diagrams under these conditions.

Even on curves is excessive slip much easier to detect in the case of locomotives with undivided adhesion. With divided adhesion, only half the wheels slip, and the locomotive retains a certain steadiness which makes the discovery of the slip much more difficult.

The reporter was very pleased with finding out this fact, which at once gave him the key to the behaviour of the H. II. Mallet locomotives : revolution counters fixed to one of the locomotives showed that there was excessive slipping in the case of the wheels driven by the low-pressure cylinders, and it was clear that in consequence of the leakiness of the high-pressure valves, which had closed rings, the pressure became too high in the intermediate receiver and too large a fraction of the tractive force was transferred to the leading set of wheels.

It then became necessary to remedy this quickly, and this was done in the following way :

The reporter had six grooves 20 millimetres ($^{13}/_{16}$ inch) wide and 6 millimetres ($^{1}/_{4}$ inch) deep turned into the " continuous ring " of the Schmidt valve (see fig. 33) and spring rings were placed in these grooves.

The success was striking, for trial runs made on the section shown in figure 16, showed that the H. II. superheated-steam locomotives used 16·7 per cent of water and 12·2 per cent of coal less, per unit of work, than the corresponding saturated-steam locomotives (1).

With this the results hitherto obtained which seemed to be against superheated steam, were brilliantly rebutted and the H. II. Mallet locomotives converted into engines working very economically. In spite of all this however, the figures obtained for the economies can only be looked on as preliminary values, which

(1) Runs made in June 1909 with locomotives Nos. 817 and 854.

will be still very appreciably improved by other improvements which will be made gradually, as has already been done with several locomotives.

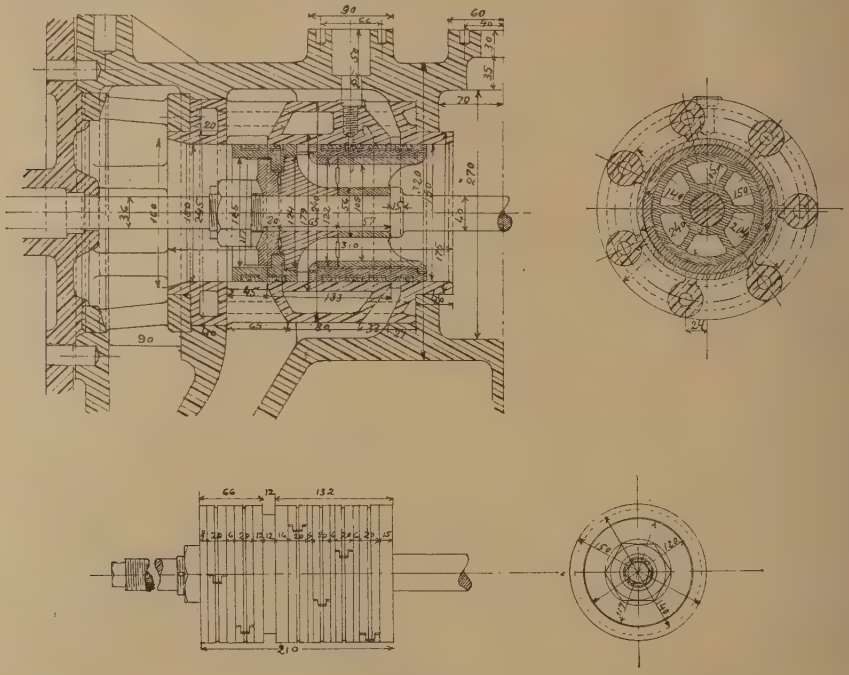


Fig. 33.

b) *Valve gear of the superheated-steam locomotives.*

All the preceding considerations show beyond doubt, that in the existing state of superheated-steam working the most important condition for real success is to have good steam-tight valves, and hence the Moscow-Kazan Railway has devoted much attention to this detail.

An important requirement is simplicity of construction, for although valves of complicated design may give good results on experimental locomotives, there is no doubt that where maintenance and supervision are difficult (as far for instance in the case of the Mallet locomotives), such valves will not give good results in the long run.

Consequently, the administration of the railway, as a result of its experience, most decidedly pronounce against the use of such a complicated design as that of the Ricour valve, already described, and shown in figure 31 *a* to *k*.

The Schmidt design with spring rings, described by Garbe (1), is used on the Б. II. and Б. k. passenger locomotives and on the A. II. goods locomotives, and on the whole gives satisfactory results. The weak points of these valves is the difficulty of grinding two ring-shaped surfaces on each side true.

For this reason, the administration does not use these valves on the Mallet locomotives, as tightness is particularly desirable in this case.

Here the valves shown in figure 33, whose defects are the thin rings, which readily break after they have become a little worn, are being replaced by the valves shown in figures 34 and 35, which were designed by Mr. L. Brunsel, assistant locomotive inspector.

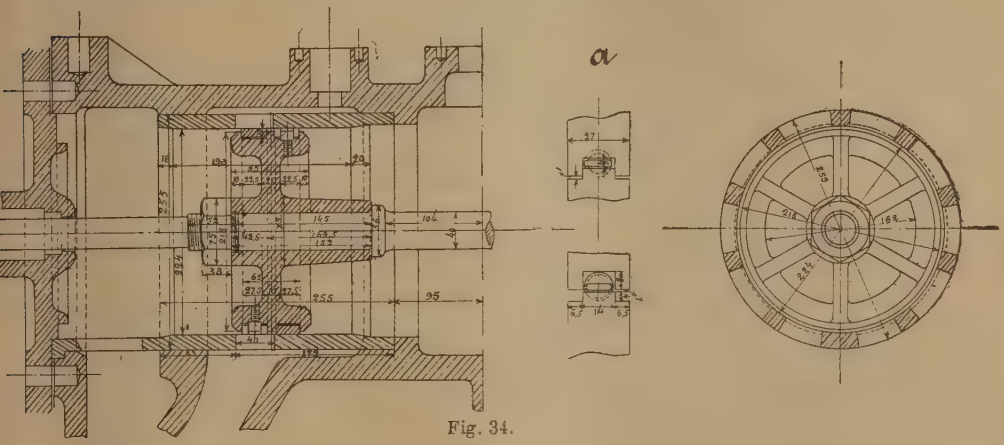


Fig. 34.

These valves consist of a piston which is in one (fig. 34) or in three parts (fig. 35); in the latter case, the insertion of the rings is easier. This piston has two rings, 27 millimetres ($1\ ^1/_{16}$ inches) wide and 10 millimetres ($^3/_8$ inch) thick. Each of these rings has a rectangular lock (fig. 34*a*), into which the flat end of a stud screwed into the piston projects, to prevent the rings from turning. As figure 34 shows, the lock of the outer ring is at the bottom, while that of the inner ring is at the top.

The heated liner of the Schmidt valve is replaced, as the figure shows, by a simple liner, and this made it possible to increase the diameter of the valve to 224 millimetres ($8\ ^{13}/_{16}$ inches).

These very simple valves work excellently, become worn but little, and remain very tight. In this valve, as in all piston valves, the most important point is good soft metal and proper tension of the rings. As figure 34*a* shows, the distance

(1) *Die Dampflokomotiven der Gegenwart*, p. 325.

between the ends of the piston rings when unconstrained is 4 millimetres ($^5/_{32}$ inch), and 1 millimetre ($^3/_{64}$ inch) when the valve is in place.

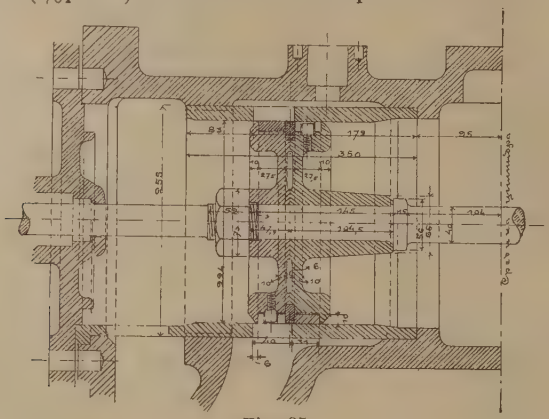


Fig. 35.

One of the H. II. locomotives has been equipped, as an experiment, with Fester high-pressure valve gear, which works very well, but has as yet shown no superiority as compared with the simpler gear just described. In order to obtain a conclusive opinion on the subject of the Fester valves, the railway administration decided to equip the fifteen passenger locomotives (figs. 26 to 28) which are being built, with these valves, and the reporter hopes to give further information about them verbally.

Valve gear of the Mallet superheated-steam locomotive.

After the " closed rings " of the original Schmidt valves on the H. II. Mallet locomotives had, as already related, been replaced by new rings, which remained tight, an opposite fault arose; while formerly the pressure in the intermediate receiver was too high, because the valves leaked, it now became too low, and consequently when running round curves the high-pressure driving gear slips too much, when heavy trains are hauled, so that, as indicator diagrams show, the high-pressure section now provides $^2/_3$ of the whole tractive force. In order to relieve it, it is necessary to increase the pressure in the intermediate receiver, and this can only be effected by reducing the cut-off in the low-pressure engine.

The position assumed by the Mallet locomotive on curves is such, that the distances m (see appendix III), and consequently also the lateral displacements of the points of support, are more favourable for the trailing three axles for the leading three axles. It is accordingly correct that a little more than half, say $^9/_{16}$, of the maximum value of the tractive force should be obtained from the points of support

of the trailing set, while the three leading axles should give $^{7}/_{16}$ of it. Now it is evident that such a delicate adjustment is only possible, if the relative cut-offs of the two engines can be altered as desired, and the alterations necessary for this purpose are at present being carried out on the H. II. locomotives. There is no doubt that when this has been done, the H. II. locomotives, with high superheat, will show better and absolutely higher efficiencies than at present, although they are already among the best locomotives of the railway, and so do not consume more water and fuel, per unit of work, than the new A. II. type (figs. 18 to 20).

It hardly sounds credible, and is yet quite true, that the water consumption of the H. II. locomotives has already been reduced by fully 40 per cent by the alterations made in the valve gear and by means of the measures, described in section II, taken to increase the superheat. This powerful locomotive now is what it was intended to be from the beginning; a proof that superheated-steam working is very advantageous in the case of Mallet locomotives, if a high degree of superheat is used.

Above all the results obtained on the Moscow-Kazan Railway with its Mallet locomotives show that every locomotive of this kind should have in its cab a pressure gauge indicating the pressure in the intermediate receiver, and also should have separate valve gear for the low-pressure and the high-pressure engine. Moreover the driver must understand how to manage the divided valve gear, so that with increased cut-off in the high-pressure engine the pressure in the intermediate receiver increases to a corresponding extent, without however exceeding the maximum permissible value, in order that there may be no excessive slip of the wheels driven by the low-pressure engine.

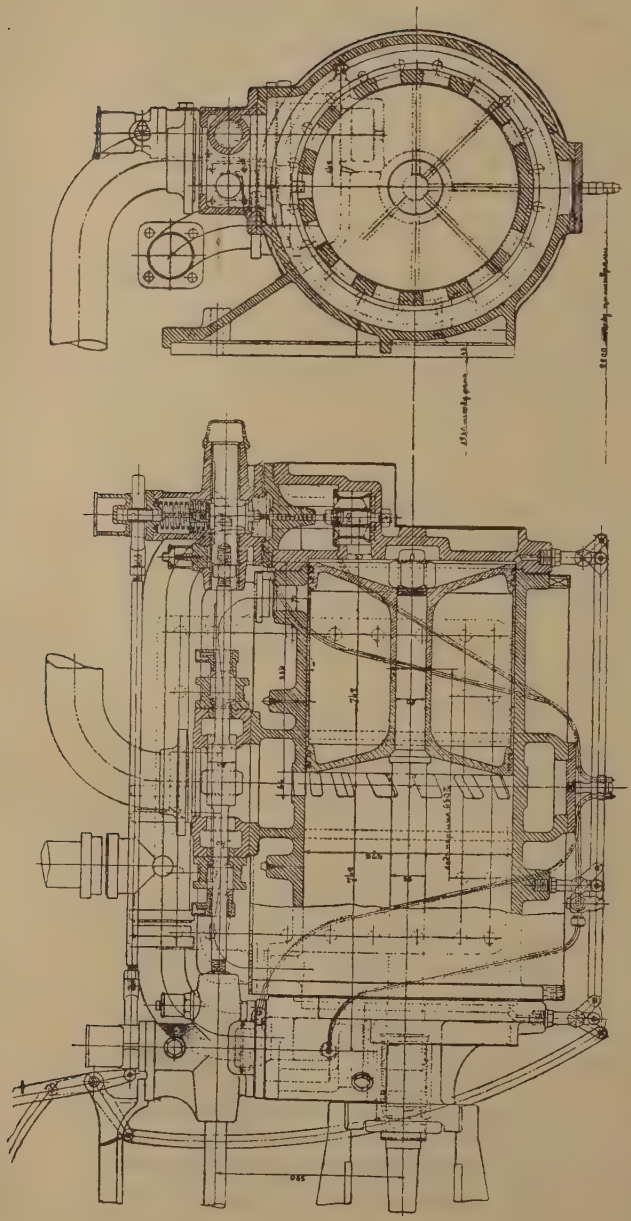
These statements show that driving locomotives with " divided adhesion " has its peculiarities which have to be learnt. On the other hand, the Mallet locomotive is more suitable than any other, if it is a question of running heavy locomotives and trains on a weaker superstructure. Under such conditions, no other design with axles having parallel displacement can replace it.

Stumpf valve gear for the superheated-steam locomotive.

One of the A. II. 0-4-0 goods locomotives (No. 520) was equipped, at Professor J. Stumpf's suggestion, with his patent slot valve gear, which is shown in figures 36 to 39.

As entrances to each cylinder, there are here two valves placed in separate boxes or chambers, cast on to the cylinder covers; the front one is shown in the longitudinal section of the cylinder (fig. 36). The steam passes through the slots in the middle of cylinder, which are covered by the long piston and uncovered by it when approaching the dead points. These slots are shown well in figure 37.

As figure 36 shows, the inside lap is only 66 millimetres (2 $^{19}/_{32}$ inches), or only 10·1 per cent, the length of stroke being 650 millimetres (2 ft. 1 $^{9}/_{16}$ inches). The



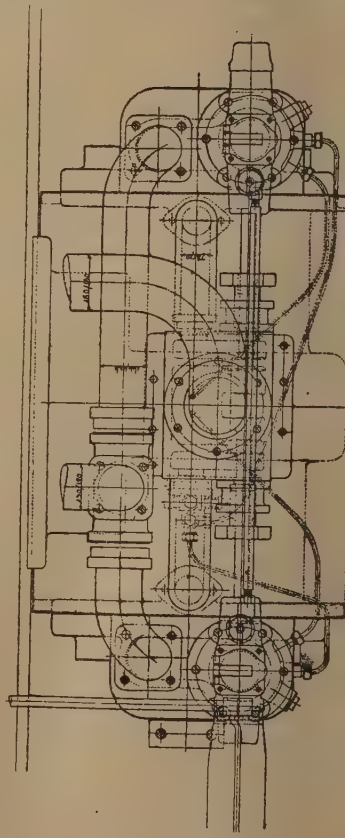


Fig. 37.

Fig. 39.

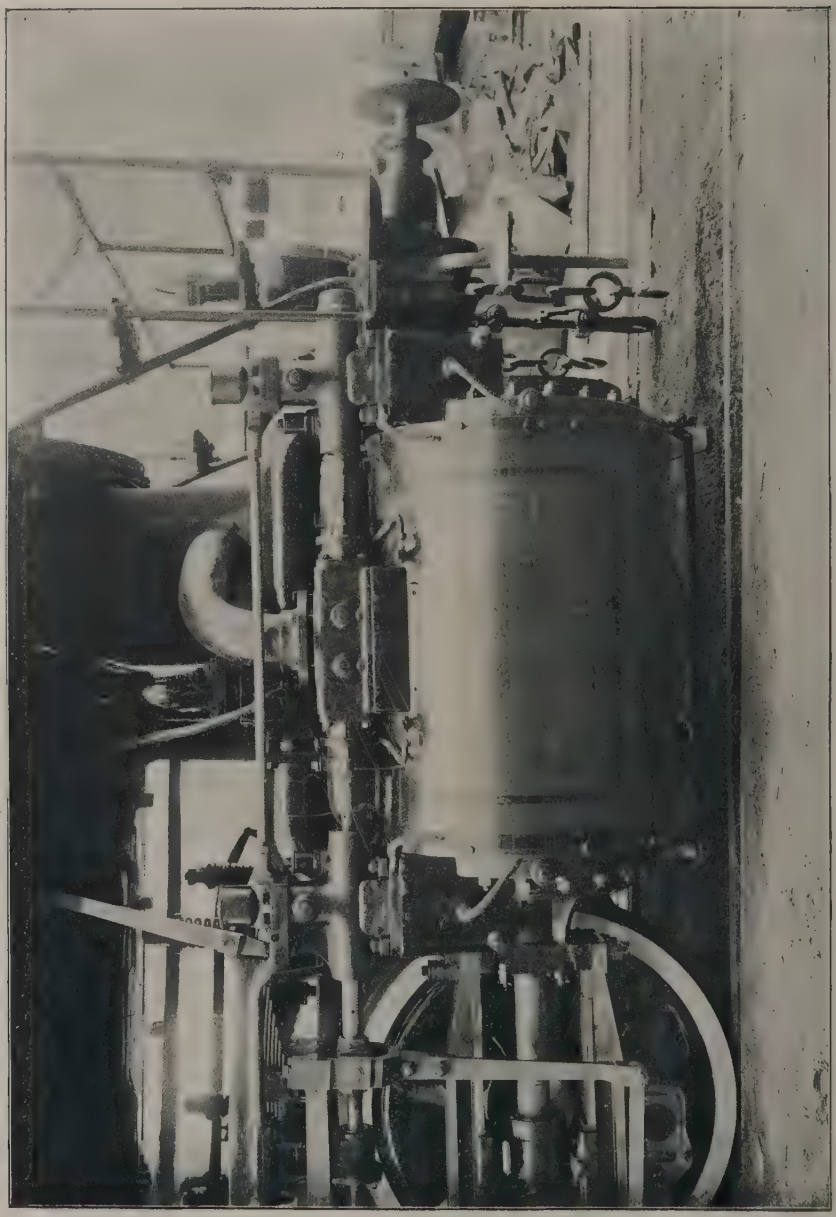


Fig. 38.

lap is only just as long during the return stroke, so that there is compression during 90 per cent of the stroke of the piston.

There are two methods for preventing too great a final pressure : either, as shown in figures 36 to 38, there is a small auxiliary exhaust valve on the valve rod, to which the steam is led from the two cylinder ends by special pipes (the openings corresponding to these pipes are clearly visible on the inner surface of the cylinder, fig. 37), or the clearance spaces are made correspondingly larger.

As figure 38 shows, the Moscow-Kazan Railway originally adopted the auxiliary valve. Later on however, the clearances were increased, by altering the piston, to 13·3 per cent, and the auxiliary valve was eliminated in the interests of simplicity.

The inlet valves are operated directly by the valve rod, by means of rollers in grooves which are milled in; these strike against bosses fixed to the valve rod guide, and thus raise the valve.

As we see, the whole arrangement is very ingenious and simple and is based on a good idea, namely to lead the steam coming in and the steam going out by different paths, and thus eliminate the bad influence of cooling by the exhaust steam.

The rod shown in figure 36 and 38 above the cylinder in front of the exhaust pipe, which can be moved from the cab by means of a lever and rod, serves for opening the valves while running with regulator closed; a device which very perfectly replaces the appliances otherwise necessary for equalizing the pressure.

The piston consists, as figures 36 and 39 show, of two light Swedish piston disks each with two Schmidt piston rings and a piece of steel tube 7 to 8 millimetres ($^{9}/_{32}$ to $^{5}/_{16}$ inch) thick held between the two disks.

At first the piston was designed by Professor Stumpf as a self-supporting piston, and the steel tube was to slide on the cylinder surface (see fig. 39).

This arrangement did not however give satisfactory results and the sliding surfaces became damaged. Accordingly the diameter of the steel tubes was reduced and a tail rod was added, so that the pistons work exactly like ordinary pistons now. The valves have now been working for seven months since this alteration was made, and the pistons have not given rise to any complaint.

Although the Stumpf valve gear gives excellent indicator diagrams ([1]) and seems in every way suitable for superheated steam, its use on locomotives cannot as yet be considered a fully-solved question. The possible advantages however are so great, that the work required to remove the defects which still exist might prove very remunerative.

([1]) The diagrams were taken it is true when the auxiliary exhaust was still there. Those taken with reduced cut-off much remind one of the gas-engine diagrams; they cannot be obtained in any such perfection with any locomotive valve gear.

Trial runs made on Rusaewka-Arapowo (fig. 16) experimental section, with trains weighing 1,000 tons (984 Engl. tons), have given the following results :

1° For the run on the whole section, the water consumption of the locomotive with Stumpf valve gear is 6·71 Russian pounds per 1,000 pood-versts (566·68 lb. per 1,000 Engl. ton-miles), while the ordinary A. II. superheated-steam locomotive with Schmidt piston valves with spring rings requires for this 7·00 Russian pounds (591·252 lb. per 1,000 Engl. ton-miles).

The water consumption of the Stumpf locomotive is accordingly *4·1 per cent less*;

2° On the Rusaewka-Paigarm section, where the cut-off is mostly 40 per cent, the Stumpf locomotive consumes more water than the ordinary, namely 17·79 Russian pounds (1,502·51 lb. per 1,000 Engl. ton-miles) as compared with 16·35 Russian pounds per (1,380·66 lb. per 1,000 Engl. ton-miles) 1,000 pood-versts, or 8·1 per cent more.

This phenomenon, which always recurs, is as yet not fully explained; it shows however that with increased cut-off the Stumpf locomotives consumes more steam than the ordinary locomotive, but that with reduced cut-off it is much superior to the latter. If we compare the two locomotives as regards the water consumption on the section Paigarm-Arapowo, we find a smaller consumption of water, of 12·1 per cent, in favour of the Stumpf locomotive, which not only makes up for the initial greater consumption, but results in the saving of 4·1 per cent mentioned under 1°;

3° The coal consumption, even for the whole section, is 6·1 per cent higher than with the ordinary locomotive.

The reason for this phenomenon, which at first sight seems peculiar (more coal for less water), is to be found in the peculiar exhaust of the Stumpf locomotive and in the nature of the coal used.

At the moment the slots are uncovered by the piston, if the cut-off exceeds 30 per cent, there is an unusually-sudden rush of steam, which has a very bad effect on the fire and produces much loss in the way of sparks, while the average vacuum is not greater than with the ordinary locomotive. No appreciable improvement has been effected in these conditions by increasing the size of the orifice of the blast pipe and by using a cylindrical chimney of greater diameter; the reporter intends to make a trial of allowing the exhaust steam to expand in a special intermediate receiver.

4° The heavy pistons produce appreciably more sideway oscillation of the locomotive, as the balancing has remained the same as in the other A. II. locomotives.

5° The exhaust slots and the opening provided at the bottom of the exhaust-steam space are very successful in keeping the cylinder free from water.

Other details used on the superheated-steam locomotives of the Moscow-Kazan Railway. — New Piston Ring. — Metallic Packing of the " Metallic Packing Co. ". — Siablow Pressure Equalizer. — Cost of Lubrication.

As it is not advisable, with superheated steam, to use piston rings with an oblique slit, which are never so tight as rings with rectangular locks, piston rings as shown

in figure 40 are made at the chief Moscow works, which give good results; in order to obtain a rectangular lock with the narrow Schmidt piston ring, a steel closing plate, 5 millimetres ($^3/_{16}$ inch) thick, is riveted to the one end of the ring. This plate also bears a projecting nose which keeps the rings from turning.

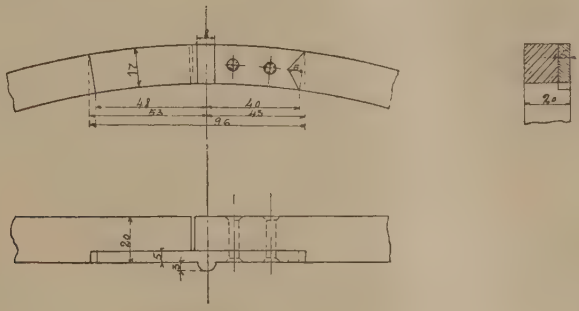


Fig. 40.

In addition, the Siablow automatic cylinder-pressure equalizer (fig. 15) is used on this railway with good results. This consists of a cylinder A, which is connected with the two ends of the steam cylinder by the pipes B and C, and of a ground-in piston D, which is kept in the lowest position by the spring E when the regulator is closed. The two ends of the cylinder thus remain connected by BAC as long as there is no pressure in the valve chest. If the regulator is opened there is pressure in the valve chest, this pressure is transmitted through pipe S into the cylinder A; the piston B rises, overcoming the pressure of the spring, into the position shown in the figure and thus shuts off the connexion between the two ends of the cylinder as long as the regulator remains open.

The Schmidt stuffing boxes work very well; besides them there are also boxes supplied by the American Metallic Packing Co. in use. These give excellent results, but cost considerable more than the Schmidt boxes.

Only mineral oil of the best quality, with a high flash-point, may be used for the lubrication of the parts in contact with the superheated steam (pistons, valves); this oil can be obtained in this country at a price which is not excessive. With a consumption of cylinder oil, with the two-cylinder locomotive, of 15 Russian pounds per 1,000 locomotive-versts (20·40 lb. per 1,000 locomotive-miles), the cost of lubrication comes to 0·25 to 0·3 copeck per locomotive-verst (0·095 to 0·114 penny per locomotive-mile).

This chapter now being concluded, the reporter wishes to express his particular gratitude to Messrs. L. Brunsel and W. Fraehn for the great readiness with which they placed their valuable assistance at his disposal both in making the numerous trial runs and in carrying out the many calculations.

Everything that has so far been said may be summarized in the statement that the Moscow-Kazan Railway considers that the introduction of superheated-steam working, with the use of the Schmidt smoke-box superheater and especially of the Schmidt smoke-tube superheater, is a very great step in advance, both from the economic (coal economy, 8 to 20 per cent; water economy, 17 to 30 per cent) as well as from the technical working (greater power) point of view.

The management of the superheated-steam locomotives has not given the employees trouble of any kind; and the administration remains of the same opinion as when the results of the first superheated-steam locomotive had been obtained, namely that it would be a wrong time for acquiring any saturated-steam locomotives, as this design is now antiquated.

CHAPTER III.

Results obtained by other railways with superheated steam working.

The administrations of the railways mentioned below had the kindness to place the information and data about their superheated-steam locomotives, which they had available, at the disposal of engineer S. Charitschkin, who had been sent on a mission for this purpose; and the reporter wishes to express his great gratitude to him.

1° *South Eastern Railway.*

The first fifteen 2-3-0 passenger locomotives equipped with the Schmidt smoke-tube superheater started running in 1906.

These locomotive have driving wheels 1,700 millimetres (5 ft. 7 in.) in diameter, cylinders 575 millimetres (1 ft. 10 $^5/_8$ in.) in diameter, a length of stroke of 600 millimetres (1 ft. 11 $^5/_8$ in.), and Schmidt valve gear with "closed rings" having a diameter of 150 millimetres (5 $^{15}/_{16}$ inches). The fire-box has a heating surface of 12·6 square metres (135·62 square feet), the 139 smoke tubes one of 101·3 square metres (1,090·41 square feet), the 18 flue tubes one of 32·68 square metres (351·77 square feet), and the superheater tubes one of 31 square metres (333·69 square feet). The grate area is 2·34 square metres (25·17 square feet) and the working pressure is 12 atmospheres (171 lb. per square inch); the weight in running order is 65·3 tons (64·2 English tons), of which 42·9 tons (42·2 English tons) come on the coupled axles.

At first the administration was fully satisfied with the working of these locomotives. The temperature of the steam averaged 300° C. (572° Fahr.), but rose on long gradients to 340° C. (644° Fahr.).

The fire-boxes had arches of refractory stone, which had however to be taken

out after a year, as the fire-box walls became burnt through, and places only showed a thickness of 2 millimetres ($^3/_{32}$ inch) near the points of support of the arch, where the fire comes out under the arch. After the arches had been removed, the temperature of the steam became materially lower; the maximum dropped from 340 to 300° C. (644 to 572° Fahr.), and the average from 300 to 270 to 280° C. (572 to 518 to 536° Fahr.), and very soon cracks began to appear in the cast-iron steam collectors, and these consequently had to be replaced by new. Only four locomotives have kept their original collectors till now; nineteen new collectors have been used for the eleven other locomotives. The steam collectors at present used are steel castings, which stand very well.

Soon afterwards cracks appeared in the steam cylinders, at the curve to the flanges by which they are fixed; it became necessary, in a short time, to replace seven right and three left cylinders.

Besides the cylinders, several driving axles and crank pins also became fractured; curiously enough there has as yet been no single case of danger to cylinder covers or of bending of connecting rods has been recorded.

According to the statements of the heads of the locomotive depots, the superheater tubes are easily cleaned, air jets being used; moreover after every nine months they are taken out of the flue tubes in order to be thoroughly cleaned.

Priming has not been observed; the drop of temperature from the collector to the cylinder is 10 to 15° C. (18 to 27° Fahr.).

The administration is not satisfied with the piston valves, and new ones with spring rings are now being substituted.

It has already been remarked that the locomotive becomes more powerful and more economic after this alteration.

In 1908 ten more passenger locomotives were acquired in which the diameter of the cylinders was reduced to 550 millimetres (1 ft. 9 $^5/_8$ in.) (1) and the length of stroke increased to 700 millimetres (2 ft. 3 $^9/_{16}$ in.). The working pressure is 13 atmospheres (185 lb. per square inch).

The railway administration considers the superheated-steam locomotives to be decidedly more powerful than the saturated-steam locomotives, and also more economic, although their coal consumption has as yet been higher than that of the compound locomotives : the resulting economy is explained by the absence of any need for double heading.

No accurate determinations of the coal and water consumptions have been made.

2° *Moscow-Windau-Rybinsk Railway.*

The first superheated-steam locomotives on this railway were acquired in 1907. These are 1-3-0 passenger locomotives built by the Putilow works; four of them

(1) Evidently because further fractures of axles and cylinders were feared.

are equipped with the Schmidt smoke-box superheater, and four others are equipped with the Schmidt smoke-tube superheater. The piston valves have a diameter of 150 millimetres (5 $^{15}/_{16}$ inches) and were fitted with closed rings.

The first difficulty which arose with these locomotives was that the sheet-iron casing in the smoke-box became burnt and became deformed so that the dampers would not work. In addition to that piston valves became damaged; either they broke, or became jammed, so that in some cases the piston rods were torn off.

An examination of these cases showed that the valve liners either had no channels, or that these were filled with coom in consequence of the use of lubricating oil of inferior quality.

The administration has accordingly decided to substitute valve with springs rings.

Of late it has rather frequently happened, in the case of the smoke-box superheater, that tubes were burnt through; this always happened in the lower part, where the tubes pass over the flue-tube opening.

Thus this burning of the tubes is chiefly explained by the collection of particles of coal, which are drawn through the flue tube. Since south Russian Gorlowka coal has been used, the superheater casing must be entirely taken out every four to six weeks and thoroughly cleaned; this is very costly and only done when superheating has entirely ceased.

The smoke-tube superheaters on the other hand give no trouble and give higher steam temperatures, averaging 290 to 300° C. (554 to 572° Fahr.), while with the smoke-box superheaters temperatures of 280° C. (536° Fahr.) at most are attained. Moreover with all the four locomotives equipped with smoke-box superheater have cracks appeared at the bends of the flanges of the flue tubes, which are riveted to the tube-plate; it consequently became necessary to take out these tubes and fit them with new ends.

The statistics kept by the railway show that the superheated-steam locomotives, as compared with the wet-steam compound locomotives, show on the average a fuel economy of 6 per cent, and much greater power.

3° *St. Nicholas Railway.*

This railway acquired its first superheated-steam locomotives in 1907. These were ten 0-4-0 goods locomotives, of the standard Russian State Railway pattern, built by the Putilow works; five were equipped with the Schmidt smoke-box superheater and five others with the Schmidt smoke-tube superheater.

These locomotives have driving wheels 1,150 millimetres (3 ft. 9 $^1/_4$ in.) in diameter, cylinders 550 millimetres (1 ft. 9 $^5/_8$ in.) in diameter, a length of stroke of 650 millimetres (2 ft. 1 $^9/_{16}$ in.), and 18 flue tubes, and the working pressure is 12 atmospheres (171 lb. per square inch).

These locomotives were followed in 1908 by three locomotives of the same 0-4-0

type, built by the Sormowo works, wequipped with Notkin superheaters in 19 flue tubes and fired with naphtha; and in 1909 by three express locomotives of the 1-3-0 type usual on this railway also equipped with Notkin superheaters and fired with naphtha, and also built by the Sormowo Works.

The 0-4-0 goods locomotives all have piston valves with "closed rings" having a diameter of 150 millimetres (5 $^{15}/_{16}$ inches), and Schmidt stuffing boxes.

The administration was very dissatisfied with the valves, as they leak considerably and become worn very quickly; it was therefore decided to fit all these locomotives with new valves with spring rings. The valves with "closed rings" only have a life of four to five months; and during the last five or six weeks before renewal the steam losses are very great.

The superheaters on the whole work satisfactorily. In the smoke-box, superheaters alone has the casing in the smoke-box often become damaged, and this led to the use of a refractory-stone lining.

The Notkin superheaters do not work so well as the Schmidt superheaters. The latter heat the steam on the average to 300° C. (572° Fahr.), the former only to 270 to 280° (518 to 536° Fahr.). In addition, the Notkin superheaters frequently require repair; for instance, 20 bend connectors had to be removed on three locomotives during a period of nine months, and although this is not in itself an expensive operation, yet it is of considerable importance as the locomotive has to be laid up for the time being.

The passenger locomotives have given particularly much trouble, as the connexions between the superheater tubes and the steam collector continually became leaky. At present it has been decided to work out a new design for these parts.

The locomotives built by the Sormowo works have piston valves with spring rings, which work satisfactorily. The administration is on the whole not satisfied with the metallic packing of the stuffing boxes, but thinks the design of the Sormowo works the better.

The administration is well satisfied with the increased power obtained from the superheated-steam locomotives.

As regards economy, it has been found that there is a saving of 4 per cent of coal in the case of the locomotives with the smoke-box superheater; the locomotives with smoke-tube superheaters, on the other hand, consume just as much coal as the wet-steam compound locomotive, and this is attributed to leakiness of the piston valves.

A Schmidt smoke-tube superheater (on locomotive No. 1190) has quite recently been replaced by a Farmakowsky smoke-tube superheater (see figs. 41 and 42), in order to compare the two systems.

The latter system is based on the alleged possibility of obtaining greater superheat by making the steam traverse in a very thin layer over the heating surface of the superheater (see fig. 43).

The trial runs made however show that this expectation is not realized, although

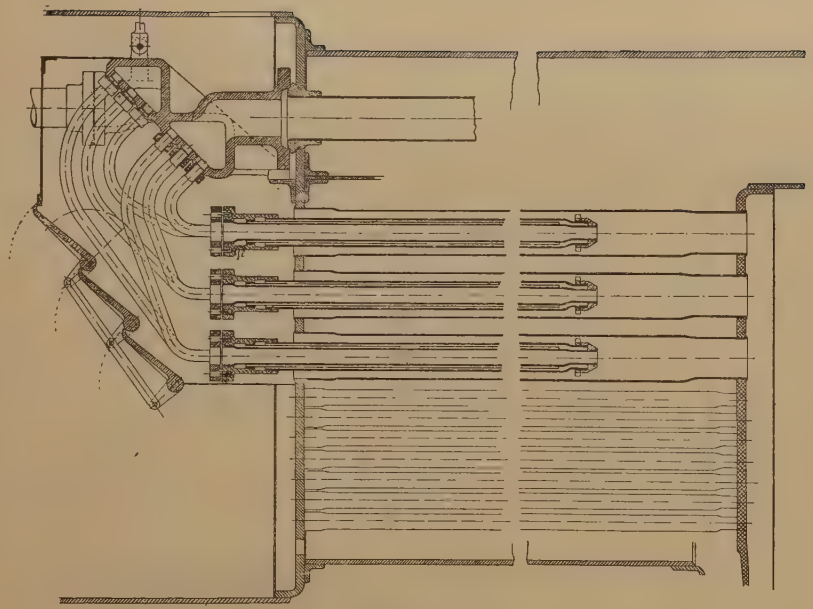


Fig. 41.

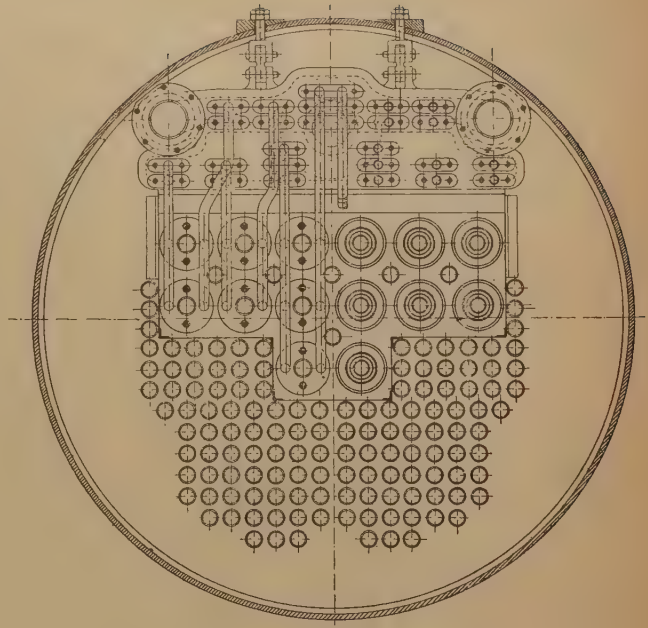


Fig. 42.

Fig. 43.

Fig. 44.

according to Mr. Farmakowsky's statement, the clear cross-section in the flue tube (8,407 square millimetres [13·03 square inches]) is greater, for the same heating surface, than in the Schmidt and in the Notkin design (Schmidt, 8,200 square millimetres [12·71 square inches]; Notkin, 6,586 square millimetres [10·23 square inches]; see fig. 44). The steam temperature attained in the Farmakowsky apparatus was 280 to 290° C. (536 to 554° Fahr.), while a temperature of 310 to 318° C. (590 to 604° Fahr.) was attained on a sister locomotive with the Schmidt superheater.

The reporter is of opinion that the superiority of the Schmidt superheater, the clear cross-section being nearly the same, depends on the circular form of the tubes which are heated from outside, and on the fact that owing to the much greater resistance inside the inner tube, only a comparatively-small quantity of the hot gases come in contact with it. A great influence on the temperature of the steam is no doubt also exercised by the fact that the current of superheated steam in the outer ring-shaped channel is cooled over its whole length by the wet steam flowing through the inner ring-shaped channel.

It is however stated that the Farmakowsky superheater does not so readily become clogged by ash and coal dust as the Schmidt superheater, and therefore would in the long run give better results, while with the Schmidt superheater the initially-high temperature becomes reduced comparatively quickly (1).

CONCLUSIONS.

1° Given the same weight and the same general arrangement, the superheated-steam locomotive is more powerful than the wet-steam locomotive;

2° Under given traffic conditions the use of superheated steam makes it possible to use heavier locomotives without disadvantage from the economical point of view. The greater reserve of power makes it possible to operate the traffic in a much more regular way without any sacrifice of economy, and this is of special importance in the case of the passenger service;

3° When properly managed, the superheated-steam locomotives consume as a rule 15 to 30 per cent less water and 8 to 20 per cent less coal than wet-steam locomotives, for an equal amount of power. The small additional cost of lubrication is comparatively unimportant;

4° The economies which can be effected depend on the design of the locomotives, the profile of the line and in particular also on what fraction of its possible power the wet-steam locomotive, which is being compared, is giving. Great advantages arise in superheated-steam working in cases where double heading is eliminated;

(1) This observation has not been made anywhere else.

5° The management of superheated-steam locomotives gives no difficulties in practice;

6° The unfavourable results obtained on some railways are not inherent as such in superheated-steam working, in its present state of development. These are special cases caused by special conditions and have long been overcome on the majority of railways;

7° Among the separate details which were at first used, the piston valve with "closed rings" gave, in particular, unsatisfactory results. On the other hand, several designs of piston valves with spring rings are already known, which give entirely-satisfactory results;

8° The improvement of the parts in contact with the superheated steam is continually progressing. The Stumpf valve gear will probably make superheated-steam working still more economic, and it is consequently advisable to try and adapt it as perfectly as possible to the conditions obtaining in the locomotive service;

9° The locomotives built on the basis of the standards set up by R. Garbe for the so-called "characteristic" of the superheated-steam locomotive, give good results in service;

10° Given a suitable design, the efficiency of the superheated-steam boiler is not smaller than that of a wet-steam boiler having an equal total heating surface. With increasing power, the comparison becomes less favourable for the wet-steam boiler;

11° Moderate superheating has proved unsatisfactory even in the case of compounds. It is desirable to attain high temperatures, up to 350° C. (662° Fahr.), in the valve chest. Loss through superheated exhaust steam is hardly to be feared;

12° The best steam pressure for superheated-steam working appears to be 13 kilograms per square centimetre (185 lb. per square inch), absolute. Hence superheated steam makes it possible to avoid the difficulties which arise with higher pressures;

13° With proper treatment, the cost of maintenance of the superheated-steam locomotive is not higher than that of the wet-steam locomotive;

14° The superheated-steam twin locomotive is in every way superior to the wet-steam twin locomotive, as well as to the two-cylinder compound locomotive;

15° The hot steam flowing through the superheater tubes at high velocity absorbs heat from the heating surface of the superheater not less readily than the boiler water from the heating surface it is in contact with. A circular cross-section, heated from outside, appears best for superheater tubes as regards absorption of heat. Superheaters in the shape of Field tubes, in which the superheated steam passes over the walls of tubes which are cooled by the wetsteam entering the superheater, give less steam and are hence not to be recommended.

APPENDIX I.

The coefficient of heat transmission of the smoke tubes of the locomotive boiler.

Professor Petrow, in one of his papers (1), concludes from trials made by Ser and from a paper published by Charles Rous-Marten in the *Bulletin of the Railway Congress* (2) on the performance of the express locomotive Dunalastair of the Caledonian Railway, that by suitable design the coefficient of heat transmission of the heating surface of the smoke tubes of a locomotive boiler can be raised to 75 heat units per square metre (27·6 British thermal units per square feet).

The author, stimulated by Professor Petrow's paper, attempted to utilize in practice the hints there given. The expected success however did not put in its apparence : the coefficient of heat transmission did not rise beyond the usual value, in spite of the high velocity of the smoke gases. This contradiction made it probable that the results of the trials made by Ser had been improperly utilized, and appeared to make it worth while to examine the results of the trials more closely.

As we know, the heat-transmission coefficient k, per unit of heating surface, depends on the resistance which there is to the transmission of the heat contained in the hot gases to the surface of the plates or tubes, on the conductivity of the material forming the heating surface, and finally on the resistance which there is to the transmission of the heat at the surface in contact with the water. It is easy to show that in a state of permanence

where k = the heat-transmission $k = \dfrac{1}{\dfrac{1}{\alpha_1} + \dfrac{s}{L} + \dfrac{2}{\alpha_2}}$ . . . . . (1)

coefficient of the heating surface, or the quantity of heat units transmitted by 1 square metre of heating surface from the hot gases to the boiler water when the difference of temperature is 1° C. ;

α_1 = the number of heat units which when the difference of temperature is 1° C. pass from the hot gases through 1 square metre of heating surface into the material the latter is composed of ;

s = the thickness of the iron plate in millimetres ;

L = the value of the conductivity of the iron plate per square metre, *i. e.* the number of heat units conducted through plate 1 millimetre thick, from one surface to the other, assuming that the difference of the temperature at the two faces is 1° C. ;

α_2 = the number of heat units which when the difference of temperature is 1° C. are transferred per hour from 1 square metre of internal surface of the boiler to the water.

In the case of iron L'' = 16·28 per second according to Newstad, and L'' = 16·40 per second

(1) " The smoke tubes of locomotive boilers " (Russian), St. Petersburg, 1897. Offprint, from the *Annals of the Imperial Technical Society*, April 1897.

(2) January, 1897, p. 3.

*

according to Angström, so that we may take the average value per hour to be L = 16·34 × 3,600 = 58,800.

As the values α_1 and α_2 must very largely depend on the state of movement of the particles of water and gas in contact with the boiler surfaces, it is readily intelligible that if the cooled gas particles and the hot water particles are not at once replaced by others, the existing differences of temperature would be much reduced, and the heat transmission would be reduced correspondingly. But as some time is necessarily required for replacing the particles in contact with the boiler surfaces by others, the transmission of the heat has to be effected through a layer of gas or water, in which the particles are being replaced more or less quickly, and the influence of the composition of this layer is expressed by the variations in the values α_1 and α_2.

Ser has found the value of $\alpha_2 = 850$, for heat delivered by an iron plate to water, which moves along it with a velocity of 0·05 metre per second. In the case of locomotive boilers α_2 must be much greater (1) as the water circulates very quickly and the steam bubbles rising produce violent eddies, so that the fraction $\frac{1}{\alpha_2}$ practically does not affect the value of the numerator in equation (1), and may be neglected.

Similarly the fraction $\frac{s}{L}$ is also comparatively very small in the case of the smoke tubes of a locomotive boiler, for if these have a thickness of 2·5 millimetres ($^5/_{52}$ inch), then

$$\frac{s}{L} = \frac{2{\cdot}5}{58{,}800} = 0{\cdot}000042,$$

a value, which as compared with $\frac{1}{\alpha_1}$, need not be taken into consideration in practice. Consequently we can, with more than sufficient accuracy, reduce equation (1) to

$$k = \alpha_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

Now as regards the value α_1, this has been determined by Ser for the quantity of heat transmitted by hot gases to the surface of iron tubes at various speeds.

For v =	0·67 metre	per second,	α_1 = 15·455 heat units.
—	1·400 metres	—	— = 22·668 heat units.
—	1·895 metres	—	— = 26·800 heat units.
—	2·244 metres	—	— = 28·143 heat units.
—	3·769 metres	—	— = 37·620 heat units.
—	4·609 metres	—	— = 42·710 heat units.

The velocities of the hot gases in the smoke tubes of locomotives are however much higher than those investigated by Ser, and the question arises, how far we can deduce the further values for α_1 from those obtained within the limits investigated.

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(1) Only in the case of badly-designed boilers, if worked very hard, can α_2 again decrease after having reached a certain maximum value, if the steam which is generated in large quantity can not rise freely to the surface of the water and can in places prevent the water from touching the surfaces which are giving off heat.

It may certainly be assumed, that α_1 cannot go on increasing indefinitely; for as v increases a limit must be reached when the heat delivered by each of the gas particles touching the tube wall is so much reduced by the shortness of the time of contact that this is no longer counterbalanced by the greater number of particles arriving in unit time.

In the figure 45 shown, the gas velocities examined by Ser are plotted as abscissae Oa, Ob, Oc ... on a scale of 50 millimetres to each metre per second of speed. The corresponding ordinates to the points surrounded by small circles represent the values for α_1, found by Ser at those speeds, on a scale of 2 millimetres to each heat unit.

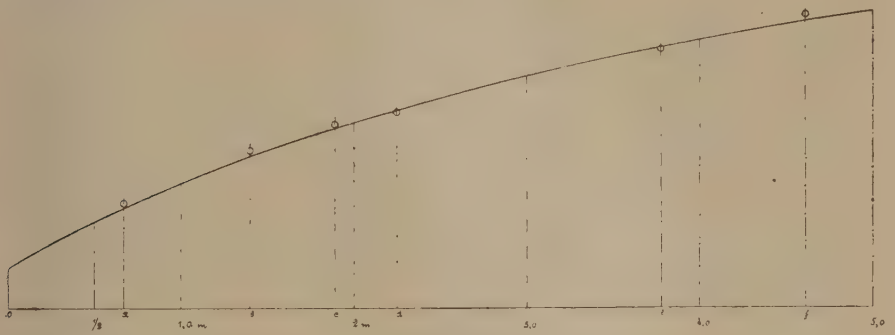

Fig. 45.

These points show a very satisfactory agreement with the curve drawn in the figure, which can be expressed by the equation

$$\alpha_1 = 18 + 36\,(1 - 0{\cdot}75^{v-1}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This equation gives the following values for α_1, at speeds beyond those which were investigated by Ser and represented in the figure :

For $v =$	6·0 metres	per second,	$\alpha_1 =$	45·5 heat units.
—	9·0 metres	—	— =	50·5 heat units.
—	13·0 metres	—	— =	52·8 heat units.
—	17·0 metres	—	— =	53·6 heats units.
—	25·0 metres	—	— =	53·96 heats units.
—	37·0 metres	—	— =	54·00 heats units.

and 54·00 then remains the value at all higher speeds.

These values agree very well with the results obtained in all the cases the reporter is acquainted with, and have received an excellent confirmation by the value of $k = 52$ deduced by Mr. Strahl from the 1904, Breslau trials.

APPENDIX II.

Heat in the hot gases. Heat absorbed by the heating surface.

The quantity of heat contained at the temperature t^0 C. in the hot gases we call the total heat. It consists of the heat $W\alpha$, which exists in the fuel and in the air which enters the place of combustion, and of the heat W produced by the combustion.

These quantities of heat we all refer to the freezing point, so that they represent the heat obtained if the substances in question are cooled to the freezing point.

If we denote by c_p the variable mean specific heat of the smoke gases corresponding to the temperature t, then

$$W' = c_p \, G_b \, B_h \, t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

is the total heat contained in the hot gases, which are obtained by burning B_h kilograms of fuel per hour, assuming that G_b kilograms is the weight of the hot gases produced by the combustion of 1 kilogram of fuel.

If we cool the hot gases to the temperature t_α, which corresponds to that of the fuel and of the air used for the combustion, we obtain the quantity of heat W, which we call the combustion heat.

If the cooling is continued to 0^0, we obtain another definite quantity of heat, which will however as a rule differ from the quantity of heat which was required to heat the air used and the fuel from 0^0 to t^0 and which we have denoted by W_α.

Only if the corresponding mean specific heat of the air and fuel between 0^0 and t^0, multiplied with their respective weights and the temperature t_α gives the same value, which we obtain by cooling the hot gases from t_α to 0^0, that is if

$$W_\alpha = c_p \, G_b \, B_h \, t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

can we put

$$W' = W + W_\alpha$$

whence

$$W = W' - W_\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now as a matter of fact the specific heat of coal, as well as that of air, is nearly the same as that of the hot gases, so that equation (3) can be considered correct for all practical purposes [1].

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[1] We would remind our readers that we understand by combustion heat the heat production of the combustion process, i. e. that quantity of heat which has to be removed from the hot gases in order to reduce their temperature to that which the fuel had before the combustion took place. The combustion heat accordingly does not contain the energy which was used for any possible processes in connection with the change of state : for only the free energy left available, after deducting the work done during change of state, is used in raising the temperature, and is obtained by cooling the hot gases to the initial temperature of the fuel.

According to Langen's experiments (1), the mean molecular heat of atmospheric air, oxygen, nitrogen, hydrogen and carbonic oxide, at constant pressure, is

$$(c'_p)_m = 6{\cdot}8 + 0{\cdot}0006\,t;$$

that of carbonic acid is

$$(c''_p)_m = 8{\cdot}7 + 0{\cdot}0026\,t;$$

that of steam is

$$(c'''_p)_m = 7{\cdot}9 + 0{\cdot}00215\,t \qquad \ldots\ldots\ldots\ldots \quad (4)$$

If we denote by CO_2, N and O the percentages by volume of the carbonic acid, nitrogen and oxygen contained in the dry hot gases, then

$$CO_2 + N + O = 100.$$

If we denote the number of molecules in a cubic metre by n, and the weight of an atom of hydrogen by ν, then the weight of a hydrogen molecule is 2ν and the weight of a cubic metre of hydrogen is $2\nu n$.

If the fuel contains H per cent of hydrogen and if μ kilograms of fuel are required order to obtain 100 cubic metres of dry hot gases, the weight of hydrogen consumed is

$$\mu \times \frac{H}{100},$$

and its volume is

$$\mu \times \frac{H}{100} / 2\nu n = \frac{\mu H}{100 \times 2\nu n}.$$

This volume is equal to the volume of the steam contained in the hot gases, for each molecule of steam contains two molecules of hydrogen, so that the number of molecules of steam is equal to the number of molecules of water. But in addition to this water there is also the water originally present in the fuel and evaporated during combustion. If the fuel contained w per cent of water, the weight of the hydrogen it contains is $\frac{1}{9} \times \frac{w}{100}$, and consequently in μ kilograms of fuel there are $\mu \times \frac{1}{9} \times \frac{w}{100}$ kilograms of hydrogen. The volume of this hydrogen is

$$\mu \times \frac{1}{9} \times \frac{w}{100} \times \frac{1}{2\nu n}$$

and this is also the volume of the steam produced out of $\mu \times \frac{w}{100}$ kilograms of water.

The total volume of the hot gases is accordingly

$$CO_2 + N + O + \frac{\mu H}{100 \times 2\nu n} + \mu \times \frac{1}{9} \times \frac{w}{100} \times \frac{1}{2\nu n} = CO_2 + N + O + \frac{\mu}{2\nu n}\left(\frac{H + \frac{w}{9}}{100}\right) \quad (5)$$

The weight of the carbon contained in CO_2 cubic metres, assuming perfect combustion,

(1) Between 0° and t°.

is evidently $\mu \times \frac{C}{100}$, where C represents the percentage (by weight) of carbon contained in the fuel.

On the other hand, the weight of the carbon contained in CO_2 cubic metres of carbonic acid is equal to the number of molecules $CO_2 \times n$, multiplied by 12 ν, the weight of the carbon contained in one molecule. Consequently,

$$CO_2 \times n \times 12\,\nu = \mu \times \frac{C}{100} \text{ and}$$

$$\mu = \frac{CO_2}{C} \times 1{,}200\,\nu n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The introduction of this value in equation (5) gives for the total volume of the hot gases

$$CO_2 + N + O + \frac{CO_2}{C} \times 6\left(H + \frac{w}{9}\right),$$

or, as $O + N = 100 - CO_2$, we have

$$(100 - CO_2) + CO_2 + \frac{CO_2}{C} \times 6\left(H + \frac{w}{9}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

It follows from this that the hot gases contain $n\,(100 - CO_2)$ molecules of oxygen and of nitrogen, nCO_2 molecules of carbonic acid and $n \times \frac{CO_2}{C} \times 6\left(H + \frac{w}{9}\right)$ molecules of aqueous vapour.

If c_p is the mean specific heat of the hot gases heated to a temperature of t^o and if 1 kilogram of fuel gives G_b kilograms of hot gases, then the heat contained in the hot gases is $G_b \times \mu \times c_p$. This heat must be equal to the sum of the heat contained in the molecules; consequently, taking (4) into consideration,

$$G_b \times \mu \times c_p = n\nu\,(100 - CO_2) \times (c'_p)_m + n\nu \times CO^2\,(c''_p)_m$$
$$+ n\nu \times \frac{CO_2}{C} \times 6\left(H + \frac{w}{9}\right)(c'''_p)_m\ (^1),$$

or, substituting for μ the value given by equation (6), we obtain

$$G_b \times c_p = \frac{C}{1{,}200}\left[\left(\frac{1{,}000}{CO_2} - 1\right)(6{\cdot}8 + 0{\cdot}006t) + 8{\cdot}7\right.$$
$$\left. + 0{\cdot}026\,t + \frac{6}{C}\left(H + \frac{w}{9}\right)(7{\cdot}9 + 0{\cdot}00215\,t)\right].$$

It follows, that for the mean specific heat of the gases we can put

$$c_p = c + \delta \times t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

---

(1) The values (4) represent the molecular heat, that is to say the specific heat multiplied by the molecular weight (the ratio of the weight of a molecule of the substance to the weight of an atom of hydrogen). If we therefore multiply the values $(c_p)_m$ with the weight ν of a hydrogen atom, we obtain the heat corresponding to the weight of one molecule.

Consequently

$$G_b \times c_p = G_b \times c + G_b \times \delta \times t \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9$$

Using the values given abore,

$$G_b \times c = 0{\cdot}5667 \times \frac{C}{CO_2} + 0{\cdot}00158\,C + 0{\cdot}0395\,H + 0{\cdot}0044\,w$$

and

$$1{,}000\,G_b \times \delta = 0{\cdot}0500 \times \frac{C}{CO_2} + 0{\cdot}0017\,C + 0{\cdot}0107\,H + 0{\cdot}0012\,w.$$

As in our case C = 67·08, H = 5, w = 18·34 and CO_2 = 11·75, we obtain

$$G_b \times c = 3{\cdot}23019 + 0{\cdot}10599 + 0{\cdot}1975 + 0{\cdot}0807 = 3{\cdot}61438 \sim 3{\cdot}6144$$

and

$$1{,}000\,G_b \times \delta = 0{\cdot}2850 + 0{\cdot}1140 + 0{\cdot}0535 + 0{\cdot}0220 = 0{\cdot}4745.$$

We accordingly find that the total quantity of heat W′ contained in the hot gases at the temperature t, corresponding to the quantity of coal burnt per hour B_h = 1·135 kilogram is

$$W' = c \times G_b \times B_h \times \left(t + \frac{\delta}{c}\,t^2\right) = Mt + Nt^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where

$$M = c \times G_b \times B_h \text{ and } N = G_b \times B_h \times \delta \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

In our case

$$W' = 4{,}102{\cdot}3440\,t + 0{\cdot}53856\,t^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

If the hot gases flow through a smoke tube of comparatively small diameter, if they flow in a thin layer over a heating surface, and if we may assume that in every cross-section of the gas there is the same temperature at all points, then the law according to which this temperature drops owing to transference of heat to the heating surface, can easily be determined.

Let us in the first place consider a volume of hot gas (see fig. 46) contained between two sections, very close together, at a distance x from the fire-box tube-plate.

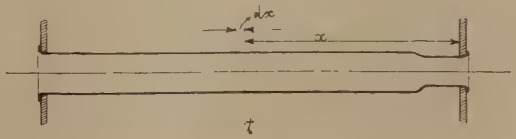

Fig. 46.

The surface of contact between this volume of gas and the heating surface is $\pi\,d\,dx$, where d is the internal diameter of the tube.

Now if t_0 is the temperature of the boiler water, k the coefficient of heat transmission (heat units per square metre for 1° C. of temperature difference), dt the change of temperature of the hot gases after touching the heating surface $\pi\,d\,dx$, and c_t the specific heat corresponding to

the temperature t, then, as the heat delivered by the hot gases must be equal to that absorbed by the heating surface,

$$- c_t \times G_b \times B_h \times dt = k\,(t - t_0)\,\pi d \times dx \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Now according to (10)

$$- c_t \times G_b \times B_h \times dt = dW' = -(M + 2\,Nt)\,dt \quad . \quad . \quad . \quad . \quad . \quad (14)$$

and consequently

$$\frac{-(M + 2\,Nt)\,dt}{t - t_0} = k\pi dn \times dx,$$

where n is the number of the smoke tubes.

The integration is very simple, if we take $t - t_0 = y$ and consequently $dt = dy$; we obtain

$$- M \log_e (t - t_0) - 2\,N\,(t - t_0) + t_0 \log_e (t - t_0) = k\pi dnx + C.$$

With regard to the determination of the integration constant, we have to note that when $x = o$, the temperature of the hot gases must be that obtaining in the fire-box at the tube-plate. If we denote this by T, then

$$(M + 2\,N\,t_0) \log_e \frac{T - t_0}{t - t_0} + 2\,N\,(T - t) = k\pi dnx \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

The left side of this equation is a temperature function, which for any given value of the variable t is equal to the product of the heat-transmission coefficient k and of the heating surface over which the gases pass to the point where the temperature is t, or $\pi dnx = H_0$.

Equations (10) and (15) are very suitable for the investigation of steam boilers. The work is much facilitated, if equation (12) is represented graphically on a sufficiently-large scale as "heat curve of the hot gases", plotting the temperatures as ordinates and the corresponding quantities of heat as abscissae. This saves the trouble of solving the quadratic equation (12) in many cases, and it is easy to find for any given value W' of the total heat, the corresponding temperature, also to determine by how many degrees the gases must be cooled, if a given quantity of heat W is to be removed from them (1).

(1) Professor Grinewetzkey's (Moscow) graphic method for the examination of steam boilers.

APPENDIX III.

The tractive force given by a locomotive on a curve.

In the mathematical investigation of such complicated phenomena as the friction of railway rolling stock on curves, much depends on a happy selection of those magnitudes or co-ordinates, which determine the position of the system to be investigated.

Up to the present, when investigating the actions between wheel and rail, the tendency has largely been to determine the position of a given wheel set M with regard to the track with the help of the magnitude of the play σ, which exists between the flanges of this wheel set and the rails, as well as of other wheel set of the same vehicles.

The reporter has found that the treatment of the question is much facilitated if the position of the wheel set which is being examined, relatively to the track, is given by the following magnitudes :

R' = length of the section OA which is produced, if from the centre of the curve O we draw a radius parallel to the given axle ab and draw from the middle of the axle A' the perpendicular A'A (on axles without radial play, A'A is at the same time the longitudinal axis of the vehicle); m = length of this perpendicular (see fig. 47).

If these two lengths are known, it is easy to determine, by several methods, both the plays σ as well as the radii of the rolling circles r_b of the outer wheel and r_a of the inner wheel.

Besides these magnitudes, it is also advantageous to introduce the distances λ_b and λ_a of the outer and inner point of support from the point A'.

The speed of the vehicle is to be denoted by its angular velocity Ω about the centre of the curve. Then the speed in the direction of the longitudinal axis of the wagon (1) is $v = \Omega R'$ metres per second.

The calculations are particularly facilitated by the introduction of the angular velocity ω of the wheel set, as an independent variable.

For ω is actually no function of Ω, as one often feels inclined to think. We can, for instance, brake an axle until the value of ω is very low, and it is a matter for theory to determine for such a value of ω the actions between wheel and rail, for instance the brake action. In the same way by acting with a given amount of steam power on the driving and coupled wheels and axles of a locomotive, a definite value ω can be obtained quite independent of the velocity $v = \Omega R'$ existing at the same time; and it is then again a matter for theory to determine the tractive force produced by this value ω (for the given value of Ω).

It is easy to see that the point of support of a wheel tire must at the same time be on the

(1) The word "axis" is used here and in what follows as the designation of a geometrical line, while the "axle" is represented by a physical body which rotates.

cylindrical surface of the rail and on the conical surface of the tread. Consequently it moves in the common plane of contact of rail and wheel tire described through the point of support.

The angle between this plane and the horizontal is equal to the taper of the rolling surface of the wheel tire if the hollow corner is not bearing against the rail. If we denote this angle by γ, then $\tan\gamma = \frac{1}{n}$, generally $\frac{1}{17}$ to $\frac{1}{20}$.

If the hollow corner is bearing against the rail, the angle of the common plane of contact depends on the lateral pressure Y. This angle we will denote by γ'.

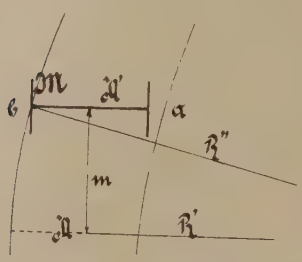

Fig. 47.

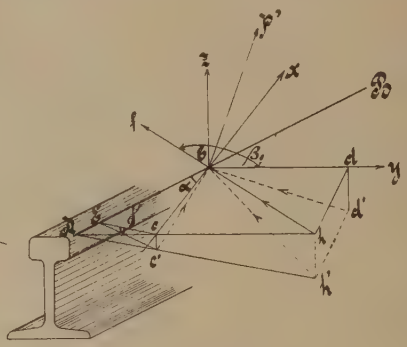

Fig. 48.

Let AB (fig. 48) be the line of contact between the common plane of ABh' and the rail, b the point of support of the wheel tire, bh' the direction of the slip of the support on the rail head at the given moment, CbZ the plane of the wheel through b, then the following magnitudes are suitably selected as ordinates : for the x ordinate the line of intersection cbw of the horizontal plane through AB and the wheel plane, where the angle A$bc = \alpha$ represents the angle of attack ; for the y ordinate the line of intersection by of the horizontal plane through AB and a vertical plane through b and at right angles to the wheel plane; for the z ordinate the line of intersection bz of the vertical planes through the x and y ordinates.

If the point h' is projected on the horizontal plane through AB to h, and if we describe through hh' two planes parallel to the coordinate planes xbz and ybz, they will intersect the x and y ordinates at the points c and d, so that hd and hc will be parallel to the x and the y ordinates respectively. The lengths cb and db are then the horizontal projections of the resulting (real) velocity of slip bh' on the corresponding ordinates, and bh is the projection on the xy plane.

It is assumed in this whole construction that there is no superelevation, an assumption which we continue in what follows. We in this way limit our investigation to the case where the centrifugal force arising at the given speed is exactly counterbalanced by the superelevation of the outer rail and where the pressure on the rail at the points of support is consequently normal to the plane, which we may imagine constructed through the upper edges of the two rails. Should the speed not correspond to the superelevation, it is easy to allow for the action of this condition by taking an additional horizontal force acting through the centre of gravity of the vehicle.

If bh' is the direction of the resulting (true) velocity of the support b in the plane ABh', and N the normal pressure on this plane produced at b, then the frictional force of fN which arises by the slipping must be in the direction opposite bh', that is to say from h' to b. Besides the vertical force P, the wheel and axle also give a horizontal force Y, acting on the point of support b. In order to fix the directions, we give the straight lines drawn in figure 48 the directions indicated by the arrows. As regards the forces P and Y, we will introduce the reactions of the rail, equal to them, vertically upwards (that is, in the direction of the z ordinate) and horizontally in the direction of the y ordinate. The horizontal projection of the frictional force in the direction $h'b$ will be on the straight line hb and in the direction from h to b. The angle ybf formed by the straight line hb and the y ordinate is of great importance in the investigation of friction at curves, and we will therefore, for the sake of brevity, denote it by β_1, as shown in figure 48. In the other cases we denote the angles formed at b by the intersection of the straight lines the letters, enclosed in brackets, denoting the corresponding straight lines: thus $(h'h')$ is the angle $h'bh$; $(h'd)$ the angle formed by the straight line hb and bd, taking into consideration the enclosed angle, $fbd = \beta_1$, and so on.

This being assumed, it is not difficult to show that the length bd, that is the horizontal projection of the resulting (true) speed of slipping bh' of the point of support b on the y ordinate is given by the equation

$$bd = m\Omega \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

It is also easy to see that the projection of the speed of slipping bh' on the x ordinate, namely cb, can be determined by the following equation:

$$cb = (R' + \lambda_b)\,\Omega - \frac{r_b \times \omega}{\sqrt{1 + \sin^2\alpha \tan^2\gamma}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Here, as already remarked, γ is the angle between the generatrix of the conical surface of the tire and the geometrical axis of the wheel set, or what comes to the same thing, the angle between the plane of contact ABh' and the horizontal.

If the tire attacks the rail, then γ' is the angle of the plane of slip ABh'. If in figure 48 we describe a plane through $c\,c'$ at right angles to AB, we have angle $cEc' = \gamma$, or $= \gamma'$ respectively.

Here it must be remarked, that in accordance with the nature of the thing, bd has in all cases the direction of the y ordinate, accordingly is positive, while bc can be from b to c, but also from b in the direction of the x ordinate, and this, according to equation (2), depends on the mutual ratio of the angular speeds Ω and ω.

Owing to the smallness of the angle α, the numerator of the second term of the right side of equation (2) can be placed $= 1$ in most cases in practice.

It follows from (1) and (2) that:

$$\tan\beta_1 = \frac{(R' + \lambda_b)\,\Omega - \dfrac{r_b \times \omega}{\sqrt{1 + \sin^2\alpha \tan^2\gamma}}}{m\Omega} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

As regards the vertical loads on the points of support, the following has to be noted: let the oads on the points of support of the axles, as determined by means of the weigh-bridge, be

Q_1, Q_2, Q_3 ... (starting with the leading axle). These loads are in reality much altered by the tractive force exercised by the locomotive, the loads on the front axles being reduced and those on the rear axles being increased. Consequently Q_1, Q_2, Q_3 ... become converted into Q'_1, Q'_2, Q'_3 ..., where difference of 2 tons and more are not rare. But Q_1', Q_2', Q_3' ..., can also not be taken as basis for the calculation of the real loads on the points of support, for large lateral forces can be transmitted on curves by the tender coupling to the frame, as for instance in the case of the locomotive shown in figures 18 to 20; these increase the loads on the outer wheels and reduce those on the inner. Let us assume, that this second condition leads to such a distribution of the axle loads Q_1', Q_2', Q_3' ..., on the corresponding wheels, that the loads on the points of support of the successive wheel pairs are P_{1b}, P_{1a}, P_{2b}, P_{2a}, P_{3b}, P_{3a} ..., where b is used to denote the outer and a the inner wheels.

The loads P_{1b}, P_{1a}, P_{2b}, P_{2a} ..., will however also not be the true ones, for we have seen that each wheel set in front of the point A (fig. 47) is displaced on the track in the direction at right angles to the longitudinal axle of the vehicle with the velocity $m\Omega$. This displacement is caused by the pressure of the axle-boxes against the shoulders of the axle journals, overcoming the corresponding component of the rail-friction and of the resistance resulting from the conical form of the wheel tire. The wheel set behind A is in the same way displaced outwards.

Hence a turning moment acts on each wheel set in the plane vertical to its axis; this we will call the vertical moment. These vertical moments add to the load of the inner wheels at the expense of the outer wheels, in the case of wheel sets in front of A (fig. 47); in the case of those behind A, on the contrary, the outer wheels are more loaded than the inner. From this we have to exclude the front leading wheel pair, the outer wheel of which is specially loaded in consequence of the action of the vertical moments. If all these factors are taken into consideration, we finally obtain the true loads on the points of support P_1', P_1'', P_2', P_2'', P_3', P_3'' ..., where the suffixes show the position of the axles, and the outer wheels have one dash and the inner two dashes.

Adopting this notation, we obtain for the normal pressure of the outer wheel

$$N' = f(P_1' \cos\gamma + Y \cos\alpha \sin\gamma). \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where Y represents the lateral force acting in the direction of the axis of the wheel pair.

Now if in figure 48 we describe hp' perpendicular to the plane ABh', then for the outer wheel

$$Y' = -K'P_1' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where

$$K' = \frac{K_0'}{K_1'} = \frac{\cos(p', y) + f\cos(h', y)}{\cos\gamma + f\cos(h', x) - U'\cos(c', x)} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and

$$U' = \frac{\cos(p', \varpi) + f\cos(h', \varpi)}{\cos(c', \varpi)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and there are corresponding equations for the inner wheel, with the difference, that the letters K, P, Y, p, c and h have two dashes instead of one (K'', P_1'', Y'' etc.).

If we also denote in succession the distance of the points of support of one and the same axle

by $S_1'S_2'$ ... and the distances of the mean forces of the axle-boxes on the shoulders of the axle journals from the points of support of the wheel tires by r_1', r_2', r_3'..., it can be proved that

$$P_1' = \frac{P_{1b} + \frac{r'}{S_1'} K'' \times Q_1'}{1 + \frac{r'}{S_1'}(K'' - K')} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and

$$P_1'' = \frac{P_{1a} - \frac{r'}{S_1'} K' \times Q_1'}{1 + \frac{r'}{S_1'}(K'' - K')} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In the equations given :

$$\left.\begin{aligned} \cos(p', x) &= -\sin\gamma \sin\alpha \\ \cos(p', y) &= \sin\gamma\cos\alpha \\ \cos(p', z) &= \cos\gamma \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and

$$\left.\begin{aligned} \cos(h', x) &= \frac{\tan\beta_1}{\sqrt{\tan^2\beta_1 + \tan^2\gamma(\sin\alpha\tan\beta_1 + \cos\alpha)^2 + 1}} \\ \cos(h', y) &= -\frac{1}{\sqrt{\tan^2\beta_1 + \tan^2\gamma(\sin\alpha\tan\beta_1 + \cos\alpha)^2 + 1}} \\ \cos(h', z) &= \frac{\tan\gamma(\sin\alpha\tan\beta_1 + \cos\alpha)}{\sqrt{\tan^2\beta_1 + \tan^2\gamma(\sin\alpha\tan\beta_1 + \cos\alpha)^2 + 1}} \end{aligned}\right\} \quad . \quad . \quad . \quad (11)$$

Similar equations exist for the inner wheel, with the difference that instead of β_1, the corresponding angle β_2 is taken.

As the magnitudes K' and K'' are used in equations (8) and (9), but depend, as equation (6) shows, on (h', y) and (h', z), in fact according to equation (11) on $\tan\beta_1$, it follows that the *true loads* P_1' *and* P_1'' *of the points of support*, vary, as equation (3) shows, as the ratio $\frac{cb}{db}$, in other words as *the ratio of the angular velocity* $\frac{\omega}{\Omega}$.

Apart from the value of the true load P_1'', to be calculated by means of equation (8), and accordingly of the true normal pressure, given by equation (4), the value of the tractive force produced in b, as figure 48 shows, also depends in another way on the ratio $\frac{cb}{bd}$. For the tractive force produced in b is nothing but the projection of the frictional force fN acting in the direction $h'b$ on the direction cb, which is parallel to the centre line of the locomotive. But it is evident that $fN\cos(h', x)$ is the greater, the greater the ratio of cb to bd, consequently, as equation (2) shows, the greater the angular velocity ω for a given value Ω. If ω becomes infinitely large, the direction of $h'b$, that is of fN, will coincide with $c'b$, and as the angle (c', c) is very small, the tractive force will nearly equal fN. In order to attain this result however, the locomotive would

have to do an infinite amount of work, and we see that this amount becomes greater and greater, the nearer the tractive force is to approximate to the value fN.

Now it is just the possibility that such an approximation may occur as regards one of the engines, while the tractive force of the whole locomotive is very far from having attained its maximum, which forms a disadvantage of "divided adhesion".

Finally it may be mentioned that the exact relation of the inclination of the angle of slip and the lateral force Y is given by the equation.

$$N' \cos(p', y) + f N' \cos(h', y) = -Y \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

We accordingly see that the angle γ' also depends on the tractive force exercised by the locomotive and becomes the greater, the smaller the tractive force. Single locomotives running light round a curve would accordingly have a greater tendency to derailment that locomotives hauling a heavy train. Similarly, running downhill is more dangerous than running uphill.

[621 .133.73, 621 .133. & 621 .134.3]

REPORT N° 6

(all countries except Russia, America, Austria, Hungary, Roumania, Bulgaria, Servia, Turkey, France, Belgium, Italy, Spain, Portugal and Great Britain)

By Karl STEINBISS,

MEMBER OF THE BOARD OF WORKS OF PRUSSIA,
MEMBER OF THE PERMANENT COMMISSION OF THE INTERNATIONAL RAILWAY CONGRESS.

The subject matter of this report is based on information sent by the administrations of the following railways :

Alsace-Lorraine Railway, Baden State Railway, Bavarian State Railway, Oldenburg State Railway, Prussian-Hessian State Railway, Saxon State Railway, Wurtemberg State Railway, Danish State Railway, Luxemburg Prinz-Heinrich Railway, Dutch State Railway (Utrecht), Dutch Railway Company (Amsterdam), Swedish State Railway, Stockholm-Rimbö-Railway, Swiss Federal Railway, St. Gothard Railway, Rhetian Railway.

The administrations of the Chinese, Egyptian, Greek, Norwegian [1], Dutch Indies and Congo railways, as well as a number of smaller privately-owned railways did not supply any information which could be utilized in this report.

The list of questions referring to subject VI, *A*, *B* and *C*, is reproduced in an appendix. In the following report the separate questions are considered in the same order as in the list of questions.

The chief types of boilers, together with their particular details considered in the different questions are shown in figures 45, 48, 51 to 61 and 64 and 65, and this information is supplemented by the figures inserted in the text.

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[1] Answers from the Norwegian State Railway only arrived after section *A* had been completed, and were inserted subsequently at the end of question 23.

A. — Boilers with smoke tubes; precautions in constructing and maintaining tubes and tube-plates.

1. *Type of boiler.* — The majority of the administrations prefer boilers with round-topped fire-box shell, which is directly connected with the circular cylindrical or conical last ring of the barrel (see figs. 51 to 53, 55 to 59 and 64 to 66).

Belpaire boilers are the chief boilers used on the Saxon State Railway; they are very usual on the Alsace-Lorraine Railway and many are also used on the Wurtemberg State Railway and the Dutch State Railway. The Prussian State Railway has 98 Belpaire boilers on its more recent locomotives; 22 are on $^{2}/_{4}$ four-cylinder express locomotives and 76 on $^{2}/_{5}$ four-cylinder express locomotive of the Grafenstaden type. Apart from this, Belpaire boilers, except on the Saxon State Railway, are but seldom used on new locomotives (see figs. 54 and 60).

Boilers with raised round fire-box top are found on the more recent locomotives of the Luxemburg Prinz-Heinrich Railway and of the Prussian-Hessian State Railway, on the $^{4}/_{4}$ and $^{5}/_{5}$ tank locomotives of the Hagans type (see fig. 61). Raised fire-box tops of other shapes are only found on older locomotives and are no longer used in the newer designs.

The usual form of narrow fire-box, placed between the frame plates, is everywhere retained. The length of this fire-box, measured at the grate, has become extended to 3·12 metres (10 ft. 3 in.). Wide fire-boxes, extending laterally beyond the frame plates, with short grate, of the American Wootten design, are used in several cases on the German and Danish railways for passenger and express locomotives, but are as yet wholly in the experimental stage; trouble frequently arises owing to leaks at the smoke tubes and defects of stay-bolts and fire-box walls. Consequently, the clear width at the bottom, formerly 2,200 millimetres (7 ft. $2\ ^{5}/_{8}$ in.), has been reduced to between 1,600 and 1,900 millimetres (5 ft. 3 in. and 6 ft. $2\ ^{13}/_{16}$ in.), and the length has been increased in order to obtain the large grate area required; this seems to give better results. The wide fire-box is also being introduced on goods locomotives.

Inclined back walls of the fire-box and shell are frequently used in the newer designs, with-boxes between the frame plates and extending beyond them. In this way, larger grate areas can be obtained without increasing the weight of the fire-box excessively. For instance, on the $^{3}/_{5}$ four-cylinder superheated steam compound express locomotives of the Bavarian State Railway, with a working pressure of 16 atmospheres, the grate area is increased to 3·28 square metres (35·30 square feet), the length being 3·00 metres (9 ft. $10\ ^{1}/_{8}$ in.). The $^{3}/_{5}$ four-cylinder passenger compound locomotive of the St. Gothard line has a grate 3·120 metres (10 ft. $2\ ^{13}/_{16}$ in.) long (see fig. 66). The bottom connexion between the fire-box and the shell is always made by a strong bar frame of rectangular section with a double row of rivets.

Instead of the riveted ring used elsewhere, the Prussian-Hessian State Railway has recently been using seamless rings, of the Ehrhardt type, with good results; good results have there also been attained, as on the Swedish State Railway, with boiler barrels with dome, with welded longitudinal seam. The latter railway has recently been using steel castings for the dome cover.

Particulars of the dimensions and of the details of the designs of the boilers are given on the figures.

2. *Stiffening the fire-box crown and connexions with the shell.* — Radial or inclined roof stay-bolts are used in order to increase the stiffness of the slightly-curved fire-box crowns of the boilers of the Baden State Railway, the Dutch State Railway, the Swedish State Railway, the Dutch Railway Company, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway, and also on the $^4/_4$ and $^5/_5$ goods tank locomotives of the Hagans type, and on a few express locomotives of the Prussian-Hessian State Railway. In all other cases, the roof stay-bolts used are arranged vertically and in parallel rows longitudinally and transversely. On the Bavarian locomotives where the bends of the fire-box side walls have a large radius (r = 220 millimetres [8 $^{11}/_{16}$ inches]), the outer side rows of the roof stays are inclined and made of larger diameter (31 millimetres [1 $^1/_4$ inches] instead of 27 millimetres [1 $^1/_{16}$ inches]). The same is the case on the Baden locomotives, with r = 260 millimetres (10 $^1/_4$ inches); here the diameter of the stays is increased from 23·5 to 30 millimetres ($^{15}/_{16}$ to 1 $^3/_{16}$ inches).

The stays in question are made of wrought iron, ingot iron and mild steel.

In order to increase the mobility of the tube-plate and to prevent cracks from starting at the front end of the fire-box roof, the front two or three rows of roof stays are replaced, on many boilers, by roof bars; on the Wurtemberg and on the Saxon locomotives, and in a few cases also on other locomotives, the two or three front rows are connected with yokes fixed to the shell, so as to be movable (see figs. 1 to 9).

Roof stay-bolts are as a rule preferred to roof bars because the stays are easy to make and put in, and the roof is more easily accessible for examination and for cleaning. They form a reliable connexion between the inner fire-box and the shell, are lighter and allow the water to circulate more freely; scale accordingly deposits less than when roof bars are used.

The methods of fixing the roof stays are shown in the figures.

3. *Cylindrical fire-boxes.* — Cylindrical fire-boxes are not used by any administration. The experiments made years ago on the Prussian-Hessian State Railway with cylindrical fire-boxes of the Lenz type, corrugated, gave unfavourable results. In course of time they lost their circular shape, and collapsed, giving rise to explosions.

4. *Combustion chambers.* — Boilers with combustion chambers are not used by any of the administrations in question.

5. *Material used for fire-boxes.* — The fire-boxes of nearly all the locomotives are made of ordinary copper. A few administrations have made experiments with

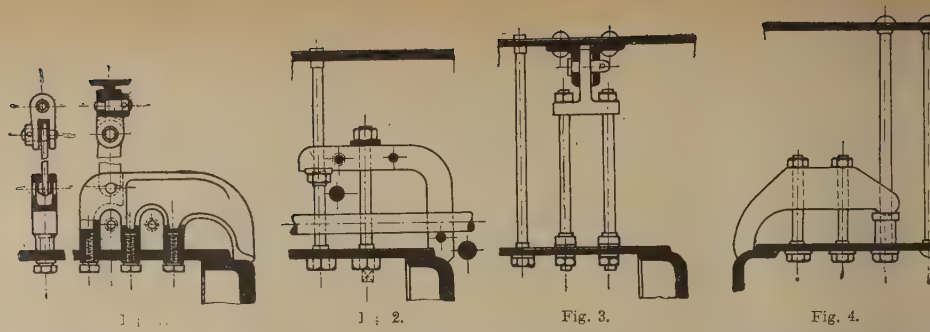


Fig. 3. Fig. 4.

Fig. 6.

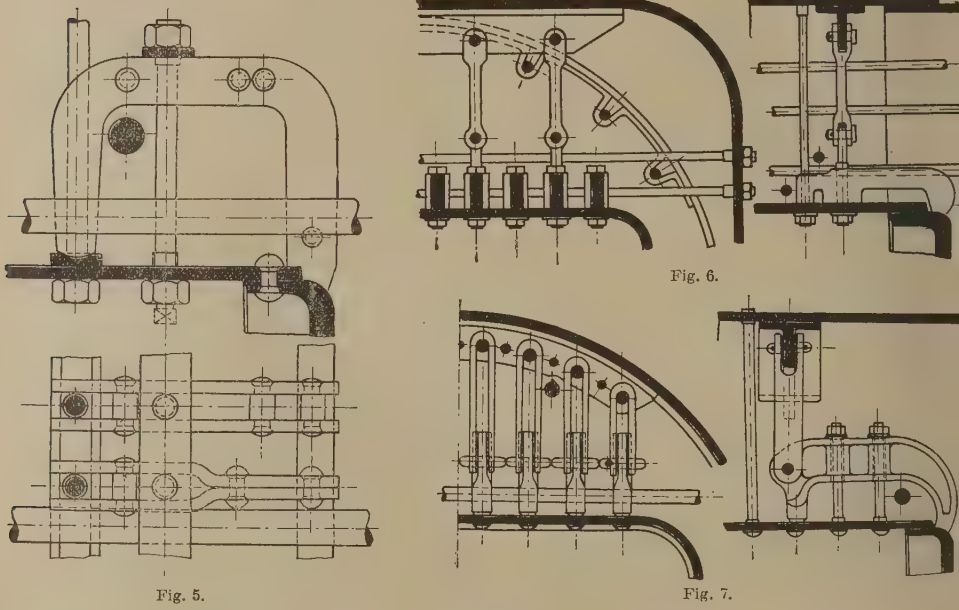


Fig. 5. Fig. 7.

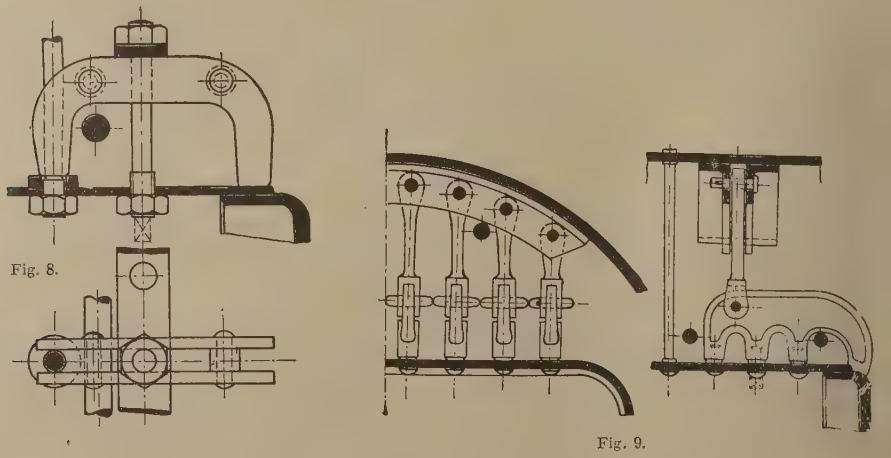


Fig. 8. Fig. 9.

Figs. 1, 2, 3, 5 and 8. — Arrangement on the Prussian State Railway.
Fig. 4. — Arrangement on the Swedish State Railway.
Fig. 6. — Arrangement on the Saxon State Railway.
Figs. 7 and 9. — Arrangement on the Swiss Federal Railway.

Figs. 1 to 9. — Arrangement of flexible stays and movable roofs of fire-boxes.

fire-boxes made of ingot iron, nickel copper and hard copper.

The Bavarian State Railway was supplied in 1900 and 1901 by the Baldwin Works, Philadelphia, with two goods locomotives and two express locomotives, which had fire-boxes made of ingot iron. The ingot-iron fire-boxes of the goods locomotives have had to be renewed after four years and then again after further three years. The second time copper fire-boxes were substituted. As regards the express locomotives, the one had its iron fire-box replaced after three years by a copper fire-box, the other after six years. The ingot-iron fire-boxes gave good results when first used; afterwards corrosion appeared inside, particularly at the points in contact with the fire, and also cracks, which started from the stay-bolt holes. The damage spread at a comparatively-quick rate, and made it necessary to do away with these fire-boxes. Further experiments have not been made.

Trials were also made with ingot-iron fire-boxes on the Saxon State Railway, during 1892-1902; in consequence of corrosion and pitting, these fire-boxes only had a short life.

The Dutch State Railway had one locomotive fitted with an ingot-iron fire-box as an experiment; but the results were not favourable.

Some time ago, a number of ingot-iron fire-boxes were used on the Danish State Railway, but they showed little durability and consequently no further experiments were made with them.

Experiments are at present being made there with iron tube-plates in copper fire-boxes, and also with fire-boxes made of " hard copper " and " special copper " supplied by the firm Heckmann of Duisburg.

The Rhetian Railway has fitted a copper fire-box with a tube-plate which is made of iron at the top and of copper at the bottom. The observations made up to the present show that the smoke tubes, both with and without copper ends, are more difficult to keep tight than with a tube-plate consisting wholly of copper.

The Prussian-Hessian State Railway has tried fire-boxes made of ingot iron and of nickel copper. Trials made with ingot-iron fire-boxes gave results which were so unfavourable, that it was decided already in 1896 that such fire-boxes should not be used. Their average life was only three years, and much less under unfavourable conditions, particularly with bad feed water; in one case the life was as little as six months. It was also found that during use cracks appeared, not infrequently, in the fire-box walls; not only was it difficult to repair them, but in a number of cases this involved much expenditure and loss of time. Although the use of ingot-iron fire-boxes has again recently been recommended in several quarters, it has been adandoned, chiefly on account of the bad result obtained in Bavaria.

Fire-boxes made of nickel copper, supplied by the firm Basse and Selve of Altena in Westphalia, were tried on a $^3/_4$ goods tank locomotive and a $^3/_4$ goods compound locomotive. The nickel content is about 15 per cent. The two fire-boxes have been in use since autumn 1905. When the goods tank locomotive was examined in July 1908, it was found that the side corners of the tube-plate had been consiperably affected by the fire, and several rivet holes showed cracks; the left corner

of the back plate showed the same defects. In order to repair the boiler and allow it to be used, it was necessary to apply copper patches, about 500 millimetres (1 ft. 7 $^{11}/_{16}$ in.) long, at the damaged spots. The side walls and the roof were still in good condition. As yet no observations are available as to the behaviour of the nickel copper fire-box of the goods compound locomotive. The observations made up to the present seem to show that nickel copper is not a suitable material for fire-boxes, for although it costs more it presents no advantage. A new locomotive equipped with a nickel-copper fire-box costs 3,600 marks (£180) more than if the fire-box is made of ordinary copper; not only does the nickel copper cost more than the ordinary copper, but the work takes longer and costs more, as the metal is harder.

The Prussian-Hessian State Railway has also started negociations with a view to trying a fire-box tube-plate made of manganese copper manufactured by the Heddernheim Copper Works.

The ordinary copper used for fire-boxes is either smelted or obtained electrolytically; but it is still doubtful whether electrolytic copper is quite as good as smelted copper, as regards durability, and resistance to burning, particularly at the corners. The Prussian-Hessian State Railway specifies that the copper plate used for fire-boxes shall have

an ultimate tensile strength of at least 22 kilograms per square millimetre (31,290 lb. per square inch) of original cross-section,

and an elongation of at least 38 per cent, measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches).

The metal to be tested may not be heated; the test pieces have accordingly to be cut and machined cold.

6. *Fire-doors.* — Most of the administrations are using single-wing swing doors; in a few cases, sliding doors in two parts, and exceptionally also drop doors opening inwards, in three parts, are used.

The doors are either circular, or oval, or rectangular with rounded corners.

The circular fire-holes vary in diameter from 300 to 450 millimetres (11 $^{13}/_{16}$ inches to 1 ft. 5 $^{11}/_{16}$ in.), the oval fire holes and the rectangular fire-holes with corners rounded vary between 300 and 360 millimetres (11 $^{13}/_{16}$ in. and 1 ft. 2 $^{3}/_{16}$ in.) in height and 375 and 500 millimetres (1 ft. 2 $^{3}/_{4}$ in. and 1 ft. 7 $^{11}/_{16}$ in.) in width. The smallest sizes found for circular doors are 300 millimetres (11 $^{13}/_{16}$ inches), on the Danish State Railway, and for rectangular doors, 300 × 375 millimetres (11 $^{13}/_{16}$ in. × 1 ft. 2 $^{3}/_{4}$ in.), on the Saxon State Railway.

In the case of wide fire-boxes extending over the frame plates the doors are generally large and rectangular, with corners rounded, having a size of about 330 × 470 millimetres (1 ft. 1 in. × 1 ft. 6 $^{1}/_{2}$ in.); or else double round or oval doors are used.

It often happened with locomotives with two fire-doors and an inclined back wall that owing to the high temperature at this wall the copper became burnt away, and it became necessary to put on patches. The substitution of one single door for the two doors will, it is hoped, prevent this.

The Baden State Railway uses for the purpose, on its most recent express loco-

motives, fire-doors which are in three parts, which open inwards, turning up; two parts only are opened at once, the side piece taking the middle piece with it. The clear door opening is 390 × 700 millimetres (1 ft. 3 3/8 in. × 2 ft. 3 9/16 in.).

The Saxon State Railway attaches importance to small fire-holes, as but little cold air is admitted and the heating surface is maintained, and uses a suitable shape of coal shovel to facilitate stoking. The Dutch State Railway considers sliding doors in two parts as the most suitable design; the Prussian-Hessian State Railway prefers the rectangular shape with rounded corners; and the Alsace-Lorraine Railway considers the oval form best for a good uniform fire.

All the administrations have on some of their locomotives fire-doors with special devices for regulating air admission at the top; this air is to assist the air which enters between the grate bars in producing as perfect and as smokeless a combustion as possible. The fire-doors are as a rule fitted on the inner side with a cast-iron or wrought-iron protecting shield, which is kept red hot by the heat in the fire-box and warms the entering air which passes over it.

The new locomotives of all kinds on the German railways are in many cases fitted with the well known Markotty and Langer smoke-consuming device (steam-jets above the grate); good results are obtained, as regards diminution of smoke, with this device (which works automatically) if properly looked after. A large number of fire doors is accordingly fitted with the circular grids necessary. The Rhetian Railway also uses that appliance. Staby smoke consumers, which are operated by opening and closing the ordinary fire-door, are also used, but only to a limited extent. Marcotty devices have also quite recently been fitted to the drop doors with lateral air admission on the Prussian-Hessian State Railway (see fig. 20).

The more recent locomotives on the Bavarian State Railway have circular fire-doors 450 millimetres (1 ft. 5 3/4 in.) in diameter, which have a small grid for air admission. On the Saxon State Railway, the air is also frequently admitted through openings in the fire-door, whose width can be adjusted by a slide. The Wurtemberg State Railway uses for the wide doors of its wide fire-boxes an air grid at the top with a sliding register; this is opened, by a catch fixed to the frame, when the door is opened, and remains open when the door is closed; it can then be closed by the driver by means of a lever of the third kind, which he generally operates with his foot. Circular air-grid wheels are also used.

On some railways the sliding door, which is in two parts, is used for admitting air, by leaving a small gap open. The fire-doors of the Swedish State Railway allow the air to enter through circular air grids.

On the Swiss Federal Railway, the swing fire-doors have circular air grids with large opening to regulate the air admission, and in order to reduce the smoke still further, there are also steam-jets above the grate. The St. Gothard Railway fits its circular doors having a diameter of 450 millimetres (1 ft. 5 3/4 in.), with adjustable register for the admission of over-grate air.

No information is supplied by the dif-

ferent administrations about trials of the numerous special devices proposed by many inventors for fire-doors and for improving the combustion.

The connection between the inner fire-box plate and the outer back plate, at the fire-hole, is generally effected, both when the back is vertical as well as when it is inclined, either by a wrought-iron fire-hole ring with a single row of rivets, which is of suitable shape; or else a dished joint is made between the two plates, with a single row of rivets (the Webb system). Neither method has given rise to leaks, but it is usual, in both cases, to use protective cast-iron rings or sheet-iron covers, which are added on the inner side, in order to reduce the action of the fire on the fire-hole joint, to prevent the burning of the rivet heads, and to protect them from being damaged by the firing tools.

The Webb design has the advantage that it is easier to obtain a tight joint than in the case of a ring joint, and the edges do not so easily come away from the rivets; on the other hand, it has the disadvantage that scale becomes deposited more readily and is more difficult to remove than with a ring joint. Attempts are made to get over this difficulty by having a special hole in the back wall over the highest point of the door frame. The Prussian-Hessian State Railway, and also some other railways, are now trying a flat fire-hole ring, which does not require the same amount of dishing as the Webb system, but it is easier to keep tight than the strong fire-hole rings hitherto used, which had a length equal to that of the stay-bolts measured between plates.

The good results obtained with the fire-holes formed of dished joints are emphasized by most of the German railways, by the Danish State Railway and by the Swedish State Railway. The Swiss Federal Railway uses chiefly the flat fire-hole ring, riveted in.

Several designs of fire-doors are shown figures 10 to 21.

7. *Ratio between total grate area, useful grate area and total tube area.* — The quality of the coal, the amount of heat produced by its combustion and the steam production of the locomotive in question determine the most suitable ratio between the total grate area R, the useful grate are R_f (*i. e.* the clear space between the grate bars) and the total heating surface of the tubes H_R.

The ratio $R : R_f$ varies between 1 : 0·16 and 1 : 0·60, and is in most cases between 1 : 0·45 and 1 : 0·56. The lowest values, *i. e.* the smallest relative useful grate areas, are given by the Danish State Railway, namely 1 : 0·16 to 1 : 0·23; the Dutch Railway Company comes next, with 1 : 0·3 for its most recent express locomotives, using Belgian coal.

The highest value, *i. e.* the greatest relative useful grate area, namely 2·71 : 1·638 = 1 : 0·6, is to be found on the $^2/_5$ four-cylinder express compound locomotives of the Prussian-Hessian State Railway. The next highest values are found on the Wurtemberg State Railway, namely 1 : 0·56 on express and passenger locomotives, and 1 : 0·54 on goods locomotives.

The ratio of total grate area to total heating surface of smoke tubes $R : H_R$ varies very much with the different locomotives, from 1 : 45 to 1 : 81. On the more recent express and passenger locomotives it is as a rule 1 : 45 to 1 : 65;

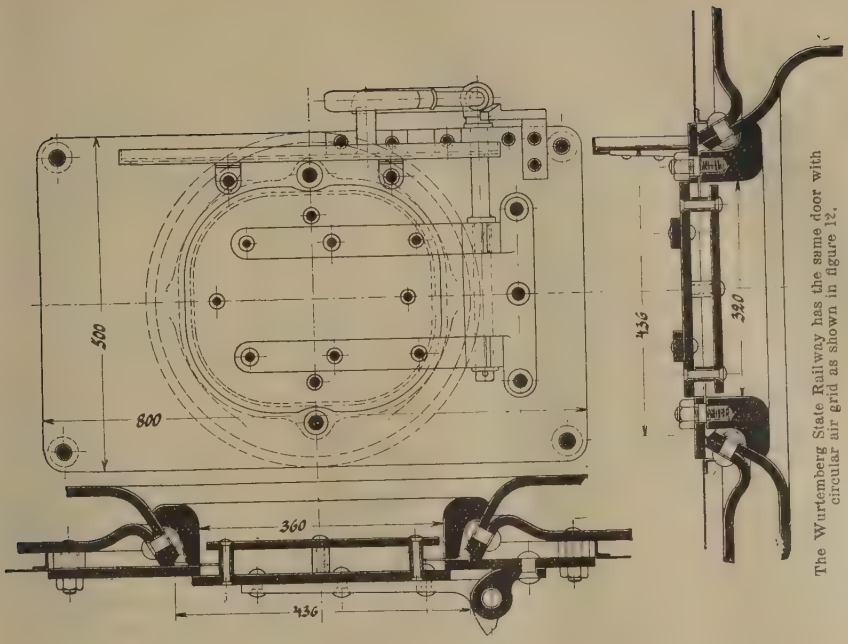


Fig. 10. — Swing door of the Prussian State Railway.

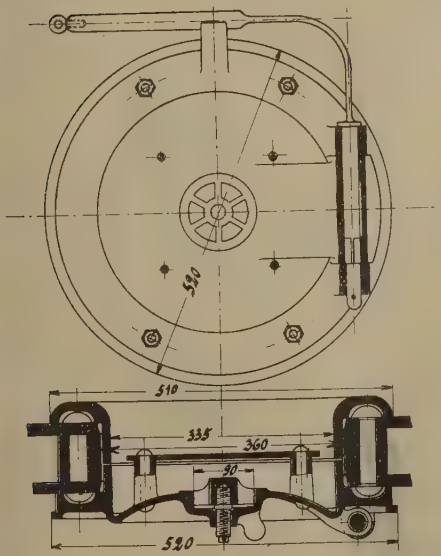


Fig. 11.

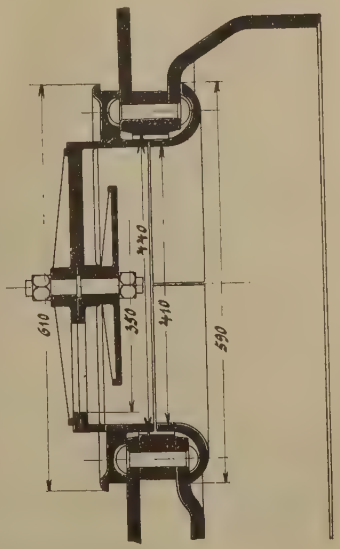


Fig. 12.

Figs. 11 and 12. — Swing doors of the Wurtemberg State Railway.

Figs. 10 to 12. — Arrangement of fire-door.

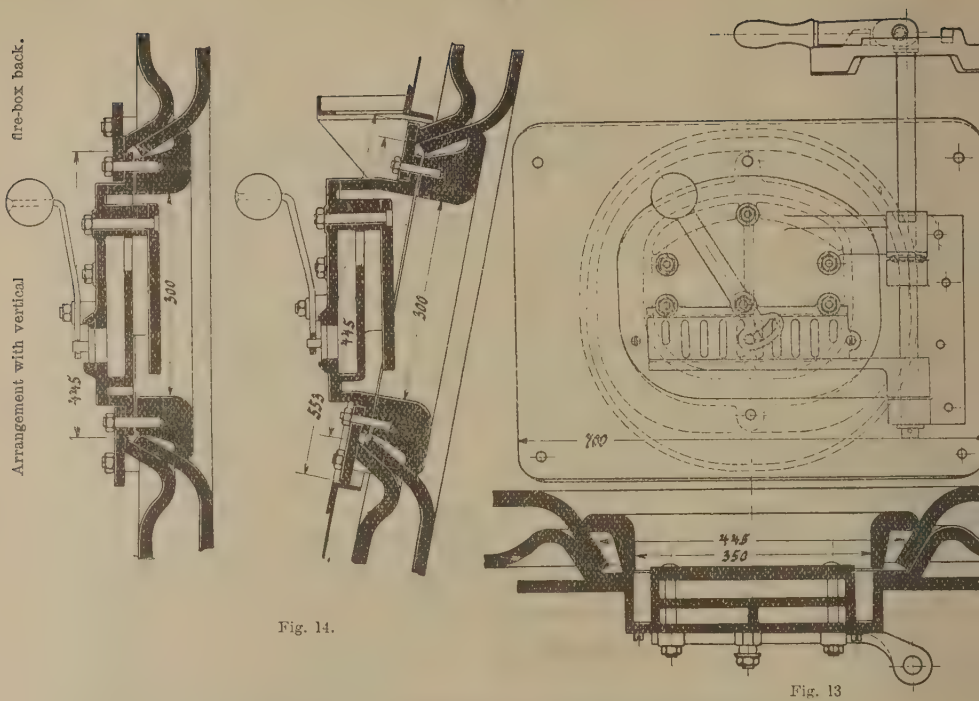


Fig. 14.

Fig. 13

Figs. 13 and 14. — Swing door of the Saxon State Railway.

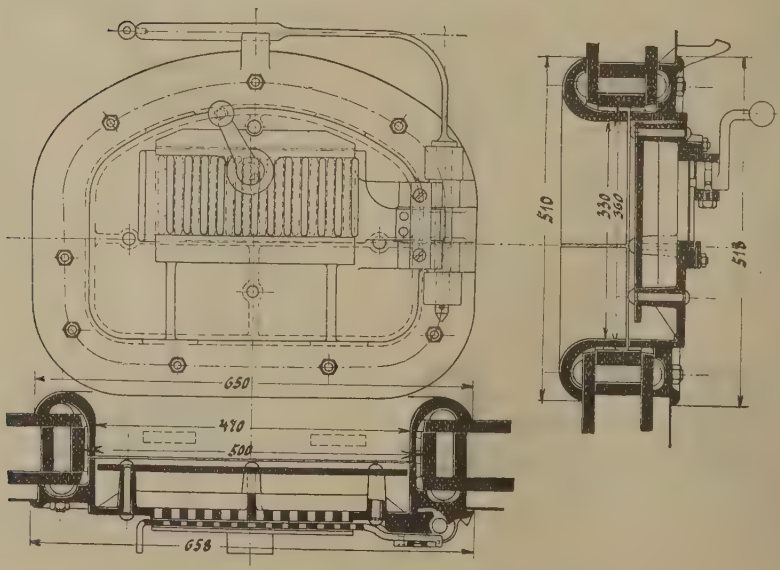
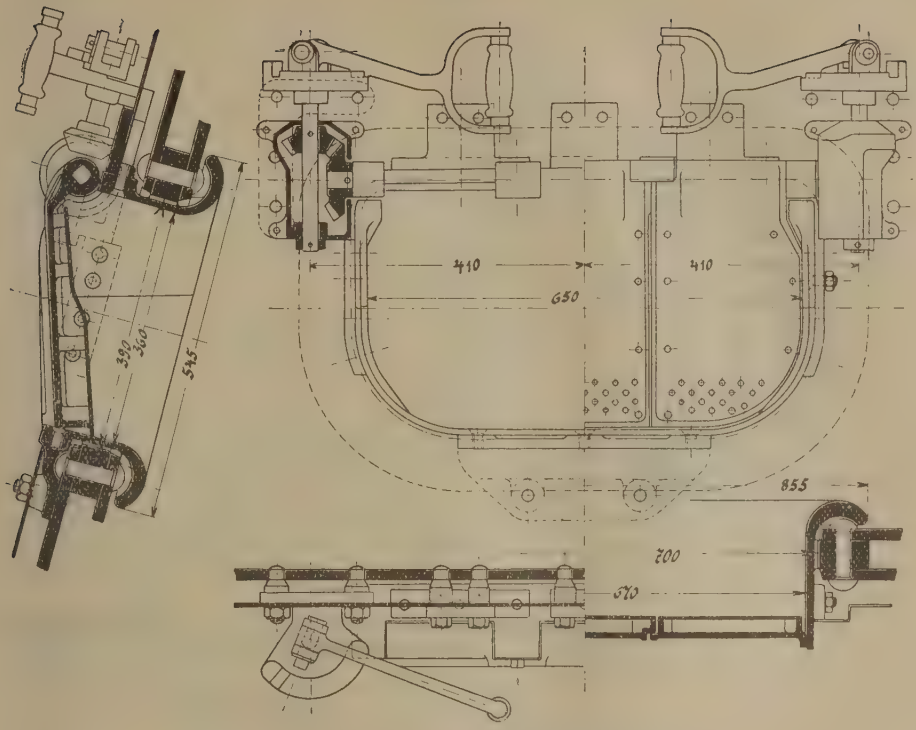


Fig. 15. — Swing door of the Wurtemberg State Railway.

Fig. 13 to 15. — Arrangement of fire-door.



Drop door in three parts, in use since 1902.

Fig. 16. — Drop door in three parts, Baden State Railway.

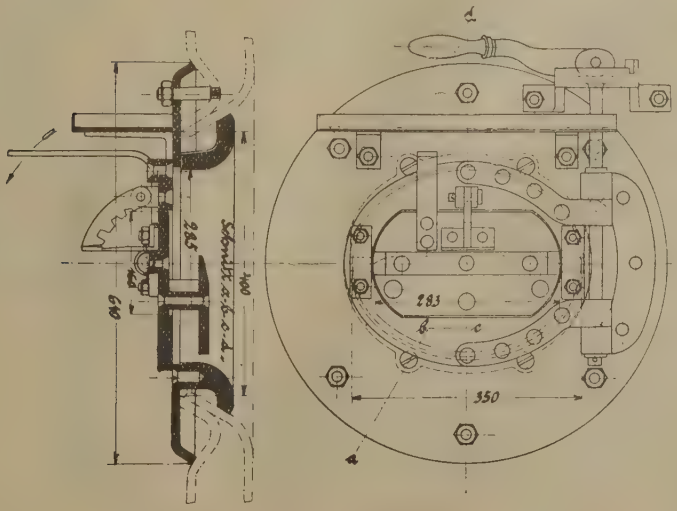


Fig. 17. — Swing door of Norwegian State Railway.

Figs. 16 and 17. — Arrangement of fire-door.

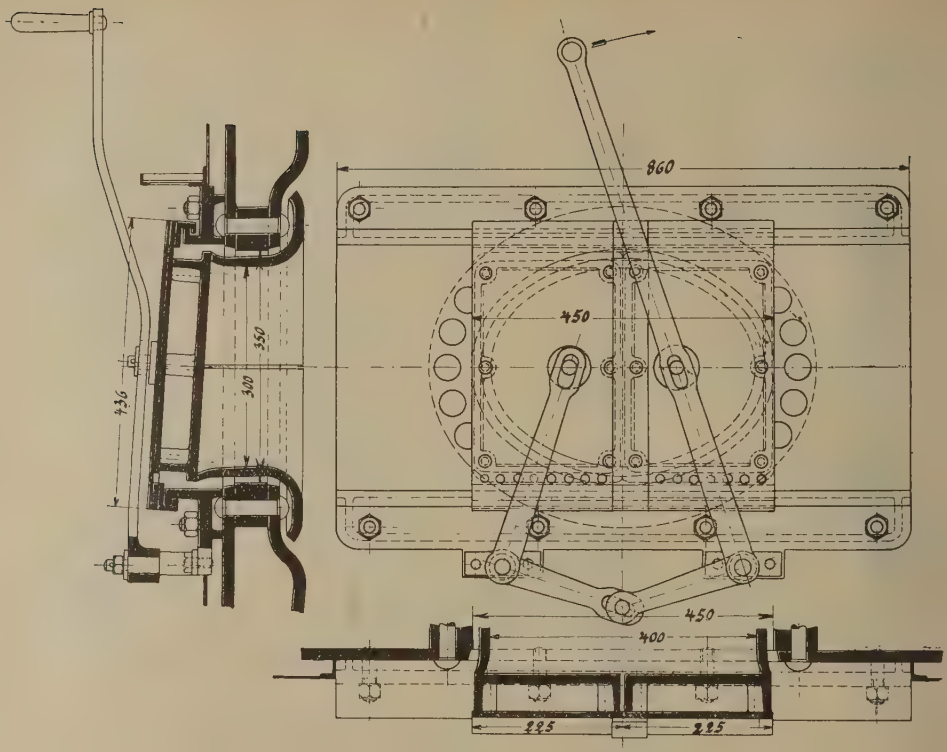


Fig. 18. — Sliding door of Baden State Railway.

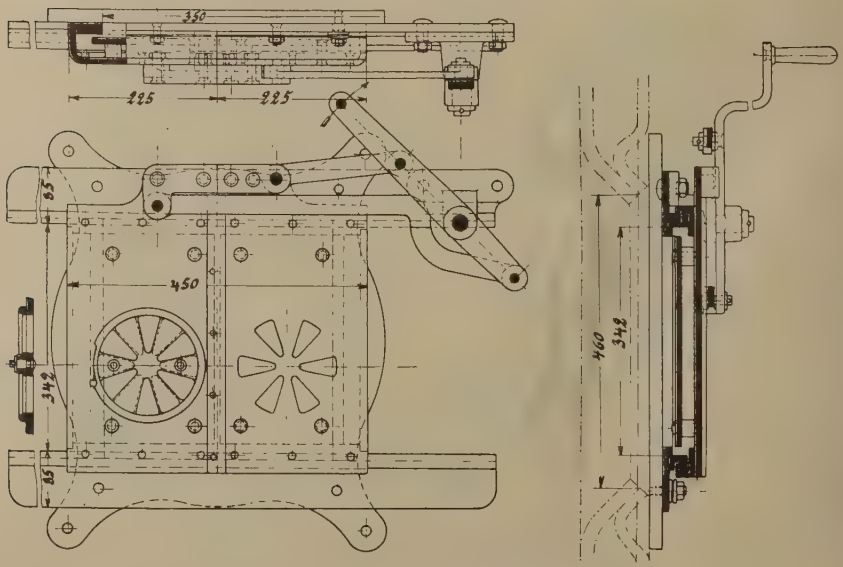


Fig. 19. — Sliding door of Swedish State Railway.

Figs. 18 and 19. — Arrangement of fire-door.

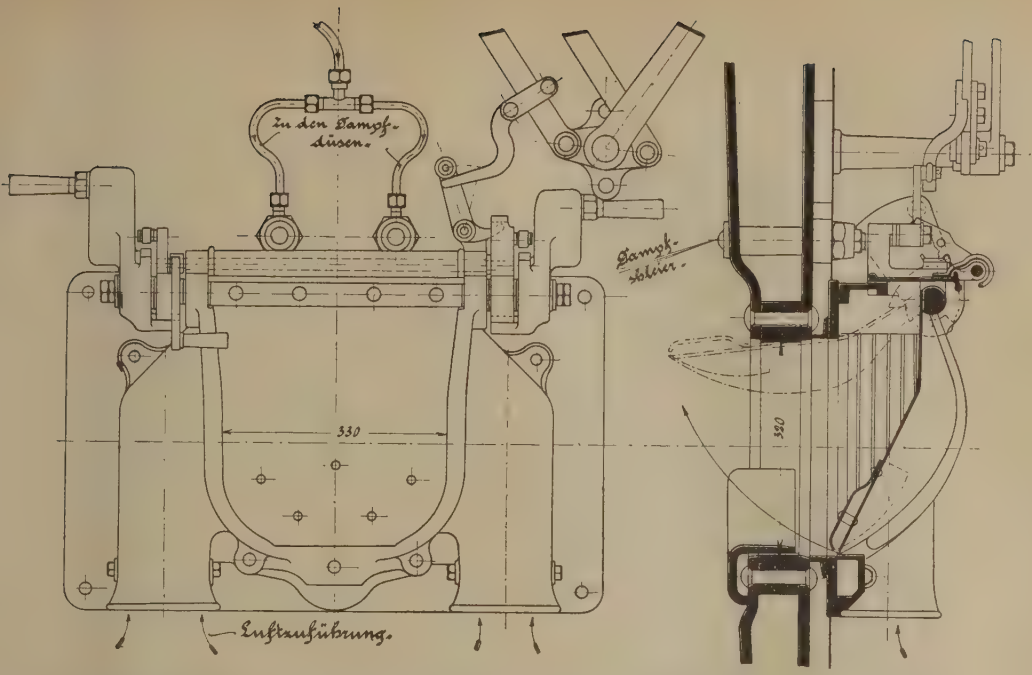


Fig. 20. — Drop door (the Marcotty latest design).

Explanation of German terms: Zu den Dampfdüsen = To the steam jets. — Dampfschleier = Steam curtain. Luftzuführung = Air supply.

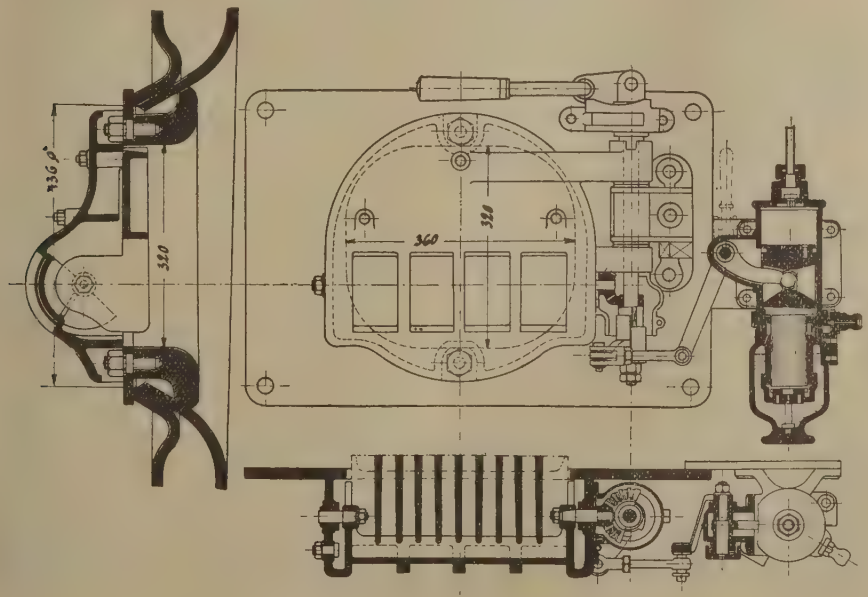


Fig. 21. — Swing door (the Marcotty design).

Figs. 20 and 21. — Arrangement of fire-door on locomotives fitted with the Langer-Marcotty smoke consumer (steam curtain). Prussian-Hessian State Railway.

rather different maximum values are to be found on the new $^2/_4$ express four-cylinder compound locomotives of the Alsace-Lorraine Railway, namely 1 : 69·5; on the $^3/_5$ passenger four-cylinder compound locomotives of the same railway, namely 1 : 70·8; and on the $^2/_5$ express four-cylinder compound locomotives of the Prussian-Hessian State Railway, namely 1 : 81·6. The latter have R = 2·71 square metres (29·17 square feet), with H_R = 221·18 square metres (2,380·84 square feet), the latter being given by 272 tubes having a diameter of 50/55 millimetres (1 $^{31}/_{32}$ inches/2 $^5/_{32}$ inches) and a length of 5,200 millimetres (17 ft. $^3/_4$ in.) between tube plate.

The largest total grate areas to be found are 4·00 square metres (43·05 square feet) on the most recent express locomotives of the Prussian-Hessian State Railway, 4·07 square metres (43·81 square feet) on the $^4/_5$ goods superheated-steam compound locomotives of the St. Gothard Railway and 4·5 square metres (48·43 square feet) on the $^3/_6$ express superheated-steam compound locomotives of the Baden State Railway.

The lowest ratio is to be found on the Saxon State Railway, with an average of 1 : 45. Most of the administrations vary between 1 : 50 and 1 : 60.

On the goods locomotives the ratio $R : H_R$ varies between 1 : 50 and 1 : 81, most of the administrations keeping between 1 : 50 and 1 : 65; the higher values are to be found on the $^3/_3$ goods compound locomotives of the Oldenburg State Railway, namely 1 : 69; on the Wurtemberg State Railway, namely 1 : 81; and on the St. Gothard Railway, namely 1 : 70.

Tank locomotives for passenger trains have, on the average, the ratio $R : H_R$ = 1 : 60 to 1 : 65, and goods locomotives 1 : 50 to 1 : 60.

In the case of superheated-steam locomotives with smoke-tube superheater, the ratio $R : H_R$ is as a rule 1 : 53 to 1 : 60, if we leave the superheater surface out of consideration, and 1 : 66 to 1 : 70 if we allow for the latter. The ratio of the total grate area to the clear cross-section of the smoke tubes varies between 6·5 and 8·0; the average is 7·0 with passenger and express locomotives and 6·5 with goods locomotives on the twin and the compound system.

In the case of superheated-steam, this ratio is about 6·5, allowing for the space occupied in the smoke tubes by the superheater tubes. In addition, the clear cross-section of the smoke tubes is reduced about 15 to 25 per cent by the reduction of the tube diameter at the fire-box tube-plate, and in the case of strongly-contracted smoke tubes, by about 35 to 42·5 per cent.

The ratio of total direct heating surface, exposed to the fire, to the total heating surface in contact with the water, is about 1 : 1·125 in the case of the wet-steam locomotive.

Drop grates or rocking grates are used on all the locomotives of the Luxemburg Prinz-Heinrich Railway, but only a few are in use on other railways. On the more recent locomotives of the Baden State Railway, part of the grate is arranged so that it can drop; this is to facilitate the removal of residues after the fire has been cleaned. The Bavarian State Railway only uses drop grates on a few small locomotives; the Saxon State Railway has grates about one third of which can drop,

for use when cleaning the fire; the Wurtemberg State Railway is putting in such grates on new locomotives; the Dutch State Railway has as yet five locomotives with drop grates; the St. Gothard Railway has eight in use; the Rhetian Railway has equipped its larger locomotives with such grates; and the Swedish State Railway has a considerable number of them. The Prussian-Hessian State Railway, the Alsace-Lorraine Railway, the Oldenburg State Railway, the Danish State Railway and the Dutch railways only use fixed grates.

Shaking grates, which are frequent on American railways, are nowhere used, but it would perhaps be advisable to pay more attention to this device in the future, as it enables the locomotive crew to clean the fire on the grate sufficiently for improving the combustion; the operation can be carried out without difficulty even while the train is running; it will make it possible to keep to time even under difficult conditions, particularly if coal producing much clinker is produced.

8. *Intermediate supports for the barrels and smoke tubes.* — The boilers of the railways we are considering generally have a length of 3,000 to 4,800 millimetres (9 ft. 10 in. to 15 ft. 9 in.) between tube-plates, and do not exceed 5,250 millimetres (17 ft. 2 $^3/_4$ in.). With boilers of these dimensions, there are no arrangements inside the barrel for supporting purposes. On the other hand, long boilers are in many cases supported externally, generally about the middle, on a saddle-shaped support fixed to the frame plates, on which the boiler is free to slide. The support consists of plate stiffened with angle-iron, or else is a steel casting; it at the same time helps to stiffen the frame transversely. The Baden State Railway and the Prussian-Hessian State Railway have latety introduced spring supports, of the compensating beam type.

The Swedish State Railway, in the case of large barrels, provides two external supports; partly in order to obtain a better distribution of the weight of the boiler over the frame, partly in order to provide againts lateral deformation of the frame plates. The Prussian-Hessian State Railway also provides two supports in the case of long barrels. The Alsace-Lorraine Railway provides an intermediate support for the barrel in the case of the large $^5/_6$ goods four-cylinder locomotives. The Danish State Railway, even when the smoke-tubes are 4,800 millimetres (15 ft. 9 in.) in length, does not provide any support for the barrel.

In no cases are any very long smoke tubes supported by partitions inside the barrel, and this occurs only incidentally in the case of boilers equipped with Pielock or similar superheaters. The vibration of such long tubes is prevented by a suitable increase in their diameter; for instance barrels from 4,900 to 5,250 millimetres (16 ft. 1 in. to 17 ft. 2 $^3/_4$ in.) in length have tubes with a diameter of 51/56 millimetres (1 $^{31}/_{32}$ in./2 $^3/_{16}$ inches), and this gives sufficient stiffness.

9. *Shape of the front tube-plate.* — Most frequently we find the flanged tube-plate, introduced into the front ring of the barrel and connected with it by riveting. Tube-plates extending to outside the front ring of the barrel are found, in addition to the other kind, on the locomotives of

the Dutch State Railway, the Dutch Railway Company, the Luxemburg Prinz-Heinrich Railway, the Stockholm-Rimbö Railway, and the Prussian State Railway. The connection with the front ring of the barrel is effected by means of an ingot-iron angle ring, and by riveting.

10. *Material for the smoke tubes.* — Most of the administrations exclusively use smoke tubes made of the best soft Siemens-Martin ingot iron, and state that these tubes give good results in practice, are to be preferred to the wrought-iron tubes formerly used, are lighter, cheaper, more durable and stronger than tubes of other metal, and are hence also safer.

The Dutch Railway Company uses wrought-iron tubes for their railways and prefers this material to mild steel, as it is less liable to corrosion.

The Luxemburg Prinz-Heinrich Railway, the Swedish State Railway and the Stockholm-Rimbö Railway use weldless tubes of mild steel and are satisfied with their life.

The different brasses formerly extensively used for smoke tubes have everywhere been given up, as they are too expensive. On the other hand, copper smoke tubes are in use on the Stockholm-Rimbö Railway, and a few years ago they were also tried on the Swedish State Railway, but in the latter case they did not show a durability corresponding to their price, and are being replaced by steel tubes.

11. *Dimensions of the smoke tubes.* — The length of the smoke tubes between tube-plates varies between 3,000 and 5,250 millimetres (9 ft. 10 in. and 17 ft. 2 3/4 in·); on most of the locomotives the length is between 3,600 and 4,800 millimetres (11 ft. 9 3/4 in· and 15 ft. 9 in.). In order that the tubes may have the stiffness necessary, their diameters are increased with the length on some scale like the following :

Length, in millimetres. . . .	3,600 / 3,950	(11′ 9 3/4″) / (12′ 11 1/2″)	4,000 / 4,250	(13′ 1 1/2″) / (13′ 11 5/16″)	4,300 / 4,550	(14′ 1 5/16″) / (14′ 11 1/4″)	4,600 / 4,850	(15′ 1 1/8″) / (15′ 11″)	4,900 / 5,250	(16′ 1″) / (17′ 2 3/4″)
Diameter external	40	(1 9/16″)	43	(1 11/16″)	45	(1 25/32″)	47	(1 27/32″)	51	(2″)
Diameter internal	45	(1 25/32″)	48	(1 7/8″)	50	(1 31/32″)	52	(2 1/32″)	56	(2 7/32″)

The thickness of the tubes varies between 2 and 2·75 millimetres (5/64 and 7/64 inch); it is 2·5 millimetres (3/32 inch) on most of the railways.

The diameter of the tubes is reduced at their fire-box ends; the contraction adopted by many administrations varies between 3 and 8 millimetres (1/8 and 5/16 inch), while some go as far as 11 millimetres (7/16 inch), in order to have greater strength in the interspaces of the fire-box tube-plate. This considerable contraction in the clear cross-section of the tubes available for the passage of the hot gases has not had a bad effect on the action of the draft; the Alsace-Lorraine Railway, the Bavarian State Railway and the Danish State Railway confirm this. The last railway contracts the clear cross-section of the smoke tubes of the most recent locomotives from 45·5 to 34·5 millimetres (1 51/64 to 1 23/64 inches), that is to say by 11 millimetres (7/16 inch) and accordingly reduces the clear cross-section by 42·5 per cent, while this reduction is only 15 to 35 per cent elsewhere. On the Swedish State Railway, it is 15 per cent.

At the smoke-box ends, all the adminis-

trations uniformly expand the diameter of the tubes by 2 to 3 millimetres ($^5/_{64}$ to $^1/_8$ inch).

In some long boilers, some of the tubes are used as stay tubes, and these generally have a diameter of 34 to 36 millimetres (1 $^{11}/_{32}$ to 1 $^{13}/_{32}$ inches) inside and 50 to 52 millimetres (1 $^{31}/_{32}$ to 2 $^1/_{32}$ inches) outside.

The larger smoke tubes used for superheating purposes have an external diameter of 119 to 133 millimetres (4 $^{21}/_{32}$ to 5 $^1/_4$ inches), and are all 4 to 4·5 millimetres ($^5/_{32}$ to $^{11}/_{64}$ inch) thick. At the smoke-box ends, they are enlarged by about 3 to 4 millimetres ($^1/_8$ to $^5/_{32}$ inch), and at the fire-box ends they are contracted by about 18 to 20 millimetres ($^{23}/_{32}$ to $^{25}/_{32}$ inch). The superheating tubes proper have an external diameter varying between 32 and 38 millimetres (1 $^1/_4$ and 1 $^1/_2$ inches) and are 3 to 4 millimetres ($^1/_8$ to $^5/_{32}$ inch) thick.

12. *Fixing the tubes in the tube-plates.* — The tubes are in the first place driven into the tube-plates so that the shoulder of the tube takes tight against the inside of the back tube-plate and then expanded by a roller expander of the ordinary type with three small rollers placed slightly conically; both ends are expanded simultaneously. The number of rollers is increased in the case of tubes of larger diameter. The Swiss Federal Railway uses for the copper ends at the fire-box, roller expanders of special type, with seven to eleven small rollers. The expanding is to be effected with as uniform a pressure, which must not be excessive, as possible, in order to avoid any deformation of the tube holes and any lateral or vertical movement of the metal forming the walls of the holes. The holes in the fire-box tube-plate are generally coned to a taper of about 1 ; 40, contracting towards the front.

The fire-box ends of the tubes which generally project 8 to 10 millimetres ($^5/_{16}$ to $^{13}/_{32}$ inch) (with some administrations only 6 millimetres [$^1/_4$ inch]) are then beaded over; either a special beading tool is used by hand, or else they are bent out by hammering with a ball hammer and then beaded by using a pneumatic hammer and a special beading tool. On the Swedish State Railway, the back ends of the smoke tubes, as far as they go into the tube-plate, are tinned outside and rolled in with a taper of 1 : 30 (see fig. 22). The St. Gothard Railway has copper ends brazed on to its tubes at the fire-box ends; these are expanded into the fire-box tube-plate and fitted with a ferrule which is beaded over so as to extend beyond the bead of the copper (see also question 14-*d*).

The tube ends at the front tube-plate project about 5 millimetres ($^{13}/_{64}$ inch); they are fixed by expanding, but are not beaded over. They are however expanded by driving in a drift having a considerable taper.

Besides the roller expanders of the well-known kinds, the Prussian-Hessian State Railway has recently been using a new expander, Kunze's patent; the smoke tubes are not only expanded into the tube-plate, but the shoulder of the iron tube is forced against the copper tube-plate on the inside of the boiler and hence makes a tight joint between the tube and the copper plate (see figs. 38 and 39).

The contraction at the back end of the

*

tube is generally produced at a red heat on a machine with a special swage and a drop hammer; but the operation is also done cold on the Lehmann smoke-tube expanding machine with multiple head.

The expansion at the front end is in every case effected by the usual method; the heated end of the tube is pushed on to the ball-shaped end of the shaft of a special machine, and a steel roller which has a vertical movement is then pressed, by means of a lever, against the walls of the tube from below. Some administrations however still use the older and simple process of using a drift by hand.

Figures 22 to 39 show different methods of securing the smoke tubes in the tube-plates.

13. *Serve tubes.* — Serve tubes are used with success on the Alsace-Lorraine Railway. The results obtained there have all been favourable, provided that the tubes have been kept properly clean. An effective method of proper cleaning consists in blowing steam through the tubes and then drawing wire brushes through, the locomotives at the time being in steam. The Dutch State Railway has also obtained good results with Serve tubes. The two administrations are accordingly satisfied with the advantages obtained with these tubes as regards good steam production, durability and strength, as compared with their higher initial cost and the somewhat higher cost of maintenance.

Less favourable results have been obtained with Serve tubes on the Baden, Prussian and Wurtemberg State railways, and on the Swiss Federal Railway. These administrations draw attention to the fact that a hard crust of soot forms on the ribbed inner surface of these tubes in a short time, which cannot be properly removed owing to the comparative inaccessibility of the inside of the tubes to the cleaning appliances, so that the initially-favourable results, as regards steam production, and the saving of coal, at first amounting to several per cent, are soon lost again; in consequence of the difficult cleaning operations, which have frequently to be repeated, and the small durability of the joints, the cost of upkeep is materially greater than in the case of locomotives with smooth tubes. They also draw attention to the fact that it takes longer to repair the locomotives, and is more difficult to utilize them properly; and taking into consideration that the Serve tubes cost considerably more, they present no advantage as compared with smooth tubes. These administrations have accordingly decided against the further use of Serve tubes and have considered it necessary, both from the technical as well as from the economical point of view, to replace the existing Serve tubes by smooth tubes.

The Swedish State Railway is at present making a trial of the so-called " corrugated tubes " manufactured by the Mannesmann works; definite results have however not yet been obtained.

14. *Corrosion of smoke tubes.* — *a*) Corrosion of iron and steel smoke tubes has as a rule only been observed in a few districts with bad feed water, and has taken the form of pitting and grooving; it is generally most strongly developed near the fire-box tube-plate and up to a distance of 300 millimetres (11 $^{27}/_{32}$ inches) from it. It seems that the chemical and elec-

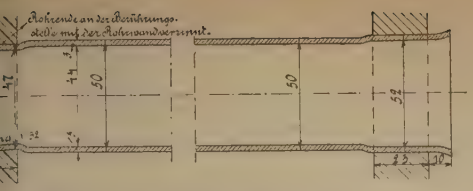


Fig. 22. — Swedish State Railway..

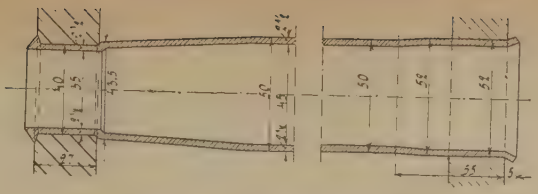


Fig. 23. — Saxon State Railway.

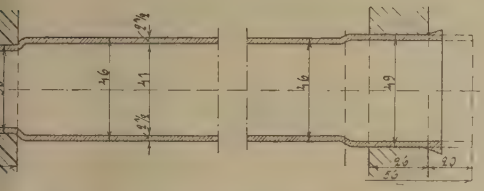


Fig. 24. — Prussian State Railway.

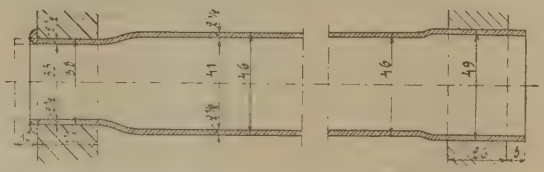


Fig. 25. — Prussian State Railway.

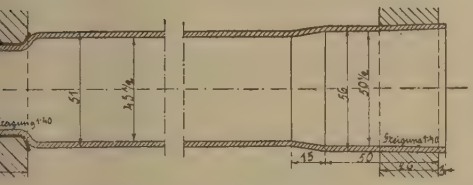


Fig. 26. — Danish State Railway.

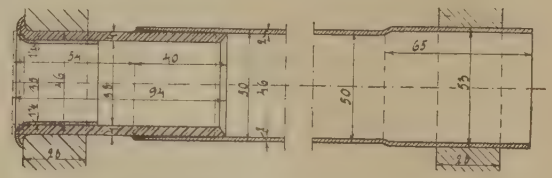


Fig. 27. — Swiss Federal Railway.

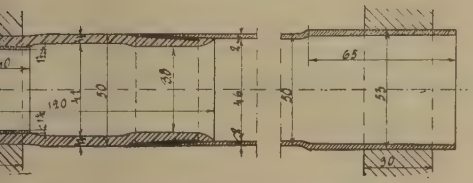


Fig. 28. — St. Gothard Railway.

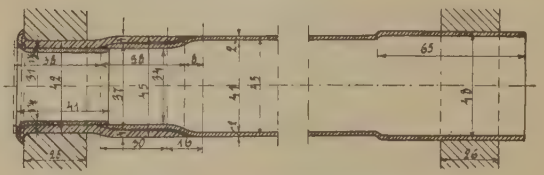


Fig. 29. — Swiss Federal Railway.

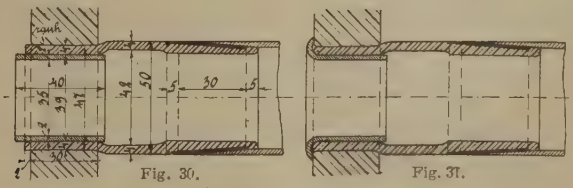


Fig. 30. Fig. 31.

Figs. 30 and 31. — Rhetian Railway.

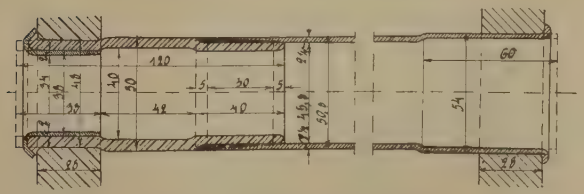


Fig. 32. — Norwegian State Railway.

Fig. 22 to 32. — Securing the smoke tubes in the tube-plate.

anation of German terms : Rohrende an der Berührungsstelle mit der Rohrwand verzinnt = End of tube tinned where in contact with tube-plate. — Steigung = Taper. — Kupferring 1 mm stark = Copper ring one millimetre ($^3/_{64}$ inch) thick. — Rauh = Bead.

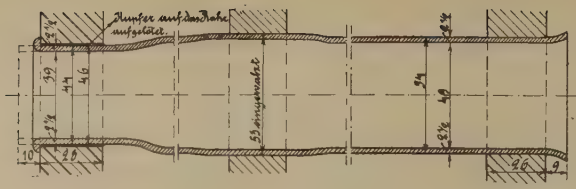


Fig. 33.

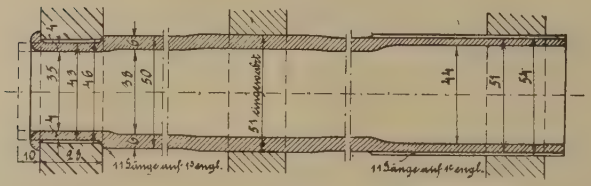


Fig. 34.

Figs. 33 and 34. — Smoke tube and stay tube for superheater of Clench-Gölsdorf type, Baden State Railway.

Fig. 35. — Smoke tube of the W. Schmidt smoke-tubes superheater.

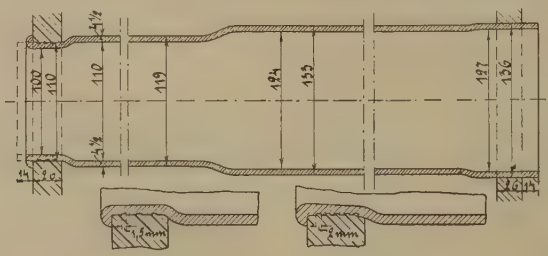


Fig. 36. Secured with three grooves.

Fig. 37. Secured with five grooves.

New method of expanding the smoke tubes in the fire-box tube-plate.

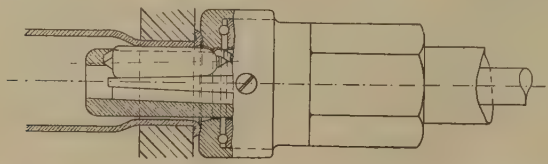


Fig. 38. — Expanding the smoke tubes into the copper tube-plate.

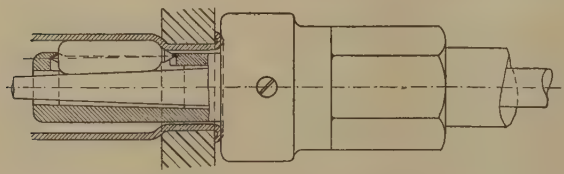


Fig. 39. — Further expanding and forcing the smoke tube against the tube-plate from the inner side of the boiler.

Figs. 33 to 39. — Securing the smoke tubes in the tube-plates.

Explanation of German terms: Kupfer auf das Rohr aufgelötet = Copper brazed to tube. Eingewalzt = Expanded. — Länge auf engl. = Threads per (English) inch.

trolytic reactions between the two metals iron and copper and the weakly-acid solutions in the water are most active under the influence of the high temperature. New tubes, which had only been three to five months in the boiler, were strongly attacked and damaged inside this zone while no traces of corrosion were to be found anywhere else. Only slight corrosion takes place if the water is of good quality. The tubes made of mild steel seem to be attacked more readily than those made of ingot iron.

b) Copper tubes have shown no particular corrosion, nor have cracks been observed. Brass tubes are not used.

c) The best means, besides frequent washing, for preventing the extensive corrosion of tubes if the water contains acids or salts and substances which form scale, is the careful purification of the feed water before it is used; this is generally recommended and is stated to give good results. Experiments with soda and other chemicals placed in the boiler did not result in reducing the corrosion.

Galvanized steel or iron smoke tubes have not been tried anywhere, but the Prussian, Bavarian and Wurtemberg State Railways have lately been trying smoke tubes made of special acid-resisting ingot iron, which are supplied by the Mannesmann works of Düsseldorf, and are made acid-resisting by a process carried out by the firm Krupp of Essen. The Dutch Railway company use wrought-iron tubes made by a special process (which is not described), which is intented to prevent corrosion.

d) Copper sleeves to the iron or steel smoke tubes, at the fire-box ends, are not used on the Alsace-Lorraine Railway. the Dutch Railway Company, the Luxemburg Prinz-Heinrich Railway, the Saxon State Railway, the Oldenburg State Railway, the Prussian State Railway, the Dutch State Railway, and the Swedish State Railway. The Danish State Railway pronounces them to be costly and unnecessary; on the other hand, the Bavarian State Railway, the Wurtemberg State Railway, the Swiss Federal Railway, the St. Gothard Railway, the Rhetian Railway and the Stockholm-Rimbö Railway prefer copper sleeves and state that they give good results both as regards tightness and durability of the joints and reduced corrosion.

The Baden State Railway considers copper sleeves satisfactory in every respect when pressures are low, but finds that with higher pressures they do not give enough resistance to deformation. The administration has accordingly adopted tubes made wholly of iron for boilers working at pressures greater than about 12 atmospheres; in the case of boilers working at a pressure of 16 atmospheres a thin copper ring is brazed on outside at the point where the tube is in the tube-plate, so as to obtain a copper-to-copper joint.

The Wurtemberg State Railway attributes the cracks occasionally found in the copper ends immediately next the tube-plate to bad quality of the copper, or to molecular changes in its structure; they praise the tightness of the joints in the tube-plate, as long as the beads are not burnt away, and in that case they restore the tightness by driving in steel rings.

The Swiss Federal Railway has not observed any real cracks in the copper sleeves, but has observed grooves inside the tubes, produced by the scoring of the

cinders. Hence as an experiment the iron tube has been contracted at the back end and a copper ring has been brazed on to the iron tube. Iron tubes without copper sleeves were also in use for a considerable time; but bad results were obtained as it frequently became necessary to expand the ends again and this damaged the interspaces of the tube-plates. It has been found that copper sleeves keep tight better;

The St. Gothard Railway also speaks in favour of copper sleeves, as tightness is maintained, and so does the Rhetian Railway, which was unable to keep the joints tight when iron tubes without copper sleeves were used.

The Swedish State Railway formerly used steel tubes with copper sleeves. They certainly kept tight better than all-steel tubes, but were less durable in consequence of the great wear which was produced at the back end of the tube by the hot gases passing through; hence they are no longer in use now.

The copper sleeves generally have a length of 100 millimetres (3 $^{15}/_{16}$ inches), but are also made up to 220 millimetres 8 $^{11}/_{16}$ inches) in length. They are turned to a taper over a length of about 35 to 40 millimetres (1 $^{3}/_{8}$ to 1 $^{9}/_{16}$ inches); a corresponding taper hole is reamed in the end of the iron tube, and the two are brazed together. This system of joining them is generally described as durable and as giving good results.

Figures 22 to 39 illustrate a number of ways of making the smoke tube ends, with and without copper sleeves, and of securing them in the tube-plates.

15. *Ferrules.* — Ferrules and liners are used regularly only by a few administrations. The Wurtemberg State Railway uses them in order to ensure the tightness of the tubes, and in the case of new tubes at those parts in the tube-plates which are most exposed to thin flames, in order to prevent the beads of the copper ends from being burnt off.

These ferrules have a taper of 1 : 15 and are 3·25 millimetres ($^{1}/_{8}$ inch) thick in the middle. Ingot-iron ferrules, without flange, were tried as an experiment, but did not give satisfactory results; their renewal was a troublesome and slow operation, for the ferrules, which in order to hold better had been slightly enlarged at the end sticking into the tube, had to be cut out by means of a cross-cut chisel, and the copper sleeves were frequently damaged during this operation. Ferrules which had not been drifted in, but only expanded by rolling, soon became loose and then could only form an inefficient protection against leaking.

The Danish State Railway, in the case of fire-boxes made of hard or special copper, use copper liners having a taper of 1 : 40 between the iron tube and the tube-plate in order to ensure a tighter joint. The ends at the fire-box are not beaded in this case; trials were made in which beaded ends gave no better results than unbeaded ends.

The Swiss Federal Railway uses ferrules 1·5 millimetres ($^{1}/_{16}$ inch) thick having a taper of 1 : 40 in order to protect the copper tube ends which have a flat flange.

The St. Gothard Railway has obtained good results with ferrules for protecting the ends of the copper sleeves against internal scoring and the copper bead from being burnt away by thin flames.

The ferrules are 40 millimetres (1 $^{9}/_{16}$ inches) long; the external diameter is 40 millimetres (1 $^{9}/_{16}$ inches), and the thickness 2 millimetres ($^{5}/_{64}$ inch) at the back end; the external diameter is 39 millimetres (1 $^{17}/_{32}$ inches) and the thickness 1·5 millimetres ($^{1}/_{16}$ inch) at the front end. The back ends of the copper sleeves are slightly beaded over, the edges of the tube holes in the tube-plate having been rounded to a radius of 2 millimetres ($^{5}/_{64}$ inch); this also is intended to help to stiffen the tube-plate.

The Rhetian Railway uses ferrules 40 millimetres (1 $^{9}/_{16}$ inches) long and having a taper of 1 : 40 in order to make the copper sleeves tighter and protect them against being burnt away.

All the other administrations dispense with ferrules and only use them exceptionally as a makeshift in the case of leaky tubes, when the ordinary method of expansion no longer works. The introduction of arches made of fire-brick, now general, has much reduced the risk of burning away the beads and tube ends, and leads these administrations to consider ferrules unnecessary; moreover, the clear cross-section of tube available for the hot gases is not reduced.

16. *Arrangement of the tubes in the tube-plate.* — All the administrations arrange the tubes in vertical rows, as the steam bubbles can rise more freely, the water can circulate better, there is greater accessibility when washing out and cleaning the boiler and when removing scale, and less scale is deposited, than when the tubes are arranged in horizontal rows.

The distance between the tubes, centre to centre, varies with the diameter of the tubes. With diameters of 40 to 45 millimetres (1 $^{9}/_{16}$ to 1 $^{25}/_{32}$ inches), the distance is 60 to 63 millimetres (2 $^{3}/_{8}$ to 2 $^{1}/_{2}$ inches); with diameters of 45 to 50 millimetres (1 $^{25}/_{32}$ to 1 $^{31}/_{32}$ inches) it is 65 to 68 (2 $^{9}/_{16}$ to 2 $^{11}/_{16}$ inches) and even 70 millimetres (2 $^{3}/_{4}$ inches); this corresponds to interspaces of 15 to 20 millimetres ($^{19}/_{32}$ to $^{25}/_{32}$ inch), measured outside the tubes.

In newer designs, the number of tubes is reduced and at the upper corners the distances are increased to 75 millimetres (2 $^{31}/_{32}$ inches) and more, so as to obtain stronger interspaces in the tube-plate and prevent cracks from forming there. They are also placed further away from the bend, in order to prevent any damage which may occur there (see fig. 40).

17. *Pressure of the steam.* — The German, Danish, Swedish and Swiss railways have all increased the working pressures of the boilers of their more recent express and passenger locomotives to beyond 12·65 kilograms per square centimetre (180 lb. per square inch) and their new superheated-steam compound locomotives all work at pressures of 13 to 16 kilograms per square centimetre (185 to 228 lb. per square inch). It has not been necessary to take any special measures for keeping the tubes tight or for the proper maintenance of the fire-box, besides generally strengthening the boiler and reducing the distances between the stay-bolts in order to prevent the fracture of the stays and the deformation of the fire-box walls. Some of the administrations, in order to stiffen the tube-plates in the case of boilers working at high pressures, use thick stay tubes screwed into the tube-

plates; about five of these stay-tubes, distributed uniformly among the other tubes, are used, having an external diameter of 50 to 52 millimetres (1 $^{31}/_{32}$ to 2 $^{3}/_{64}$ inches) and an external diameter of 32 to 34 millimetres (1 $^{17}/_{64}$ to 1 $^{11}/_{32}$ inches). Attention is drawn to the fact that everything depends on the proper treatment of the fire and of the feed-water gear.

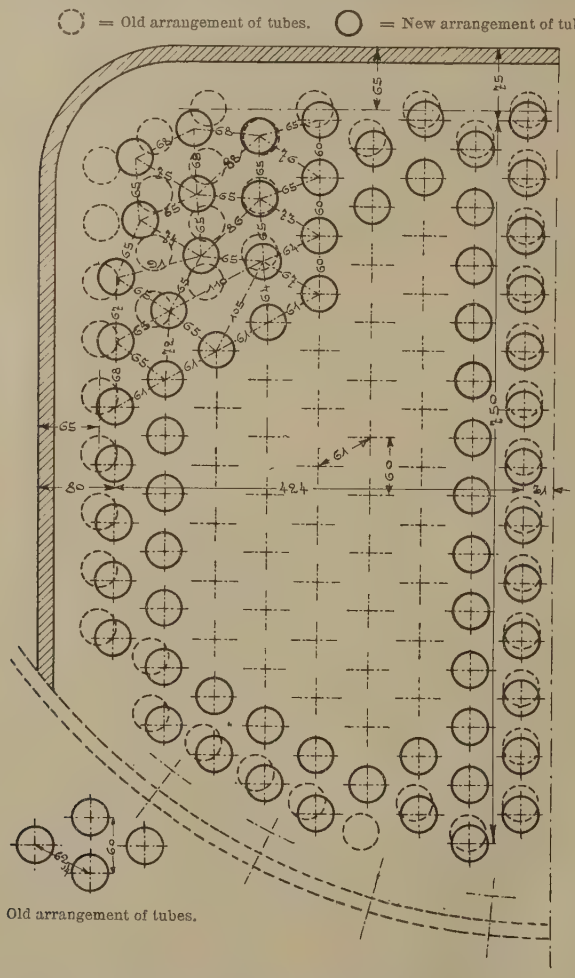


Fig. 40. — Altered arrangement of the tubes on the $^{2}/_{4}$ passenger compound locomotives of the Prussian State Railway.

On goods locomotives and tank locomo-

tives, the pressure is nearly always 10 to 12 kilograms per square centimetre (142 to 171 lb. per square inch), and this is only seldom exceeded, for instance on the goods locomotives of the St. Gothard Railway which work at up to 15 kilograms per square centimetre (213 lb. per square inch).

The St. Gothard Railway draws attention to the fact that with pressures of 15 kilograms per square centimetre (213 lb. per square inch) and upwards, the use of ferrules has also proved satisfactory for keeping the tubes tight.

The Prussian-Hessian State Railway, in the case of their $^2/_5$ four-cylinder express compound locomotives, working at pressures of 14 to 16 kilograms per square centimetre (199 to 228 lb. per square inch), had to renew the fire-box tube-plates at an early date owing to cracks in the tubes, and the smoke tubes also frequently showed leaks; but the experience gained up till now, shows that this is not to be attributed to the high pressures so much as to the design of these locomotives, which have wide fire-boxes extending beyond the frame plates. Here again special care is taken with the firing and with the washing out of the boiler in order to reduce the damage to which the tubes and the fire-box are more liable when the pressures are high.

The Dutch State Railway, the Dutch Railway Company, the Luxemburg Prinz-Heinrich Railway and the Stockholm-Rimbö Railway only have boiler pressures which do not exceed 12·65 kilograms per square centimetre (180 lb. per square inch).

The introduction of superheated steam checked the tendency to use high boiler pressures; the pressure adopted for express and passenger locomotives was as a rule 12 kilograms per square centimetre (171 lb. per square inch), and below 12·65 kilograms per square centimetre (180 lb. per square inch) in the case of twin engines. More recently however, the Saxon State Railway, the Bavarian State Railway, the Baden State Railway, the Wurtemberg State Railway, the Swiss Federal Railway and the St. Gothard Railway have again been constructing superheated steam compound locomotives with higher boiler pressures; for instance 16 kilograms per square centimetre (228 lb. per square inch) on the Bavarian $^3/_5$ express four-cylinder locomotives with superheater.

18. *Spacing of the tubes and stays. Hammering the copper of the fire-box tube-plate.* — The spacings given under questions 16 are looked upon as satisfactory; but with the newer boilers, in order to prevent the fractures which often occur in the interspaces of the upper corners of the tube-plate, one does not go so near the bends, and the spaces between the tubes are made larger at the upper corners of the fire-box tube-plate, as may be required, slightly reducing the number of the tubes. The total heating surface of the tubes is thereby reduced by about 4 per cent (see fig. 40).

The spaces left between the stays have been materially reduced in the newer locomotives, if only on account of the increased boiler pressure; the distance, centre to centre has been reduced to about 90 millimetres ($3\ ^9/_{16}$ inches), and some administrations have reduced it to 85 to 80 millimetres ($3\ ^{11}/_{32}$ to $3\ ^5/_{32}$

inches), the shank of the bolt having a diameter of 19 to 22 millimetres ($^3/_4$ to $^7/_8$ inch).

The process of hammering the copper tube-plates in order to harden them is carried out on the Alsace-Lorraine Railway, the Danish State Railway, the Dutch Railway Company, the St. Gothard Railway and the Rhetian Railway. On the Swiss Federal Railway, some of the tube-plates are hardened by hammering, with others, the tube holes are drifted open in order to compress the metal; but no special advantages has been observed.

The Alsace-Lorraine Railway hammers the metal in order to make it denser, and finds that it then gives less when the tubes are expanded; the latter then hold better and leaks do not start so readily.

The Danish State Railway is making trials with Hartmanns's special copper.

The Dutch Railway Company as a rule hammers all copper tube-plates and obtains satisfactory results.

The St. Gothard Railway hammers all parts on the fire-box side cold, except the roof curves, and obtains good results, and so does the Rhetian Railway.

19. *Extended smoke-boxes. Prevention of sparks.* — Extended smoke-boxes are used on the newer locomotives of most of the railways and are up to 2·7 metres (8 ft. 10 $^5/_{16}$ in.) in length. The exceptions are the Saxon State Railway, the Wurtemberg State Railway, the Stockholm-Rimbö Railway, the St. Gothard Railway and the Rhetian Railway. The advantages which are recognized are that a more uniform vacuum can be kept up in the extended smoke-boxes and that is there is more room for cinders, without the capacity of the smoke-box becoming too much reduced. It is also easier to find room for other appliances (connecting tubes, superheater, spark arrester, etc.); fewer sparks are ejected and the more uniform draft results in a saving of fuel.

Spark arresters of various kinds are used for preventing the ejection of the sparks from the chimneys. They consist of flat screens made of sheet metal (with long or circular holes) or made of wire netting (one or two or three rows of round or angular wire placed over each other); or else are funnel-shaped, filling the space between the blast pipe and the chimney, and made of flat bar, angle iron, wire work, or loose wire loops connected together like chain mail. Locomotives which are fired with lignite or peat have, besides these spark arresters, also spark catchers of onion or other shape placed on the chimney so as to catch any sparks which may have passed through the spark arrester (see figs. 41 to 43).

The utility of these devices and their effect on reducing the power of the sparks to set fire to any thing depend chiefly on the nature of the coal, and its behaviour when being burnt under the conditions of draft normally obtaining on the locomotives in question, and accordingly the clear spaces in the screens, etc., also vary extensively; we find used long openings measuring 50 × 6 millimetres (1 $^{31}/_{32}$ in. × $^1/_4$ inch), round openings having diameters of 8 and 10 millimetres ($^5/_{16}$ and $^{13}/_{32}$ inch), galvanized wire netting made of wire 2·5 millimetres ($^3/_{32}$ inch) in diameter, with a mesh of 6 millimetres ($^1/_4$ inch), and others.

As a rule, these spark arresters reduce the ejection of sparks, the larger red-hot

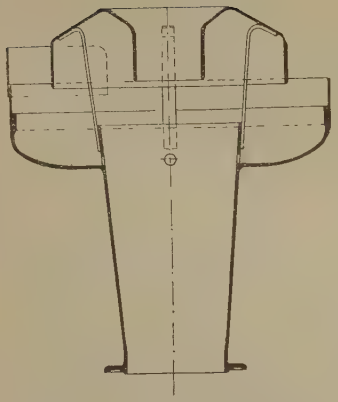


Fig. 42. — Saxon State Railway.

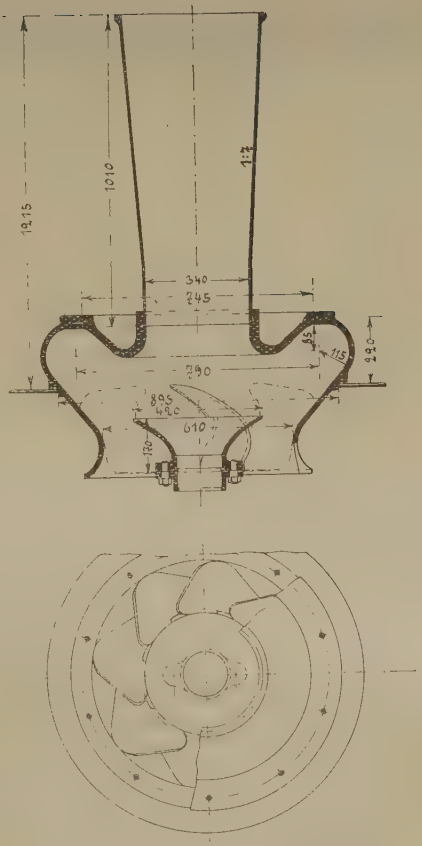


Fig. 41. — Swedish State Railway.

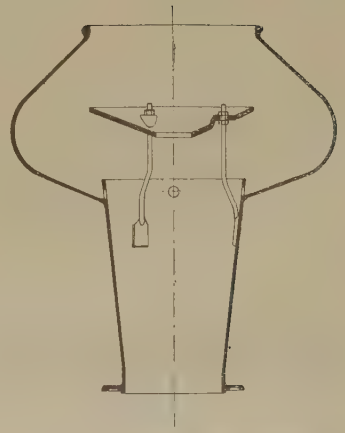


Fig. 43. — Saxon State Railway.

Figs. 41 to 43. — Special forms of chimney for light fuel (peat and lignite)

cinders being kept back in the smoke-box or broken up; but they do not make it possible altogether to stop the emission of the sparks, which is sometimes attended with very costly consequences. The great heat and the variations in the temperature soon produce warping effects, and together with the comparative weakness of the parts, only make it too easy for a larger opening to form. Special attention must therefore be devoted to the proper inspection of these appliances while in use, and to their proper construction and adjustment at the workshops. Moreover, there is not one of these devices which is absolutely certain not to become blocked, at all events partly, particularly if the tubes are not quite tight and the ash becomes damp; they then interfere with the proper draft.

The Swiss Federal Railway has accordingly given up the use of special spark arresters of this kind on its newer locomotives, and has placed deflector plates in the smoke-box instead; these as a rule give good results and interfere less with the draft. The Danish State Railway also uses deflector plates. Deflector plates are largely used in America and these give very good results, as the author has had opportunity to observe; it would be well worth making a more extended trial of them in Europe.

There is nothing new, as regards the joint of the smoke-box door, which must be made perfectly air-tight in order to prevent internal combustion and consequent warping; but it may be mentioned that on many of the more recent locomotives the smoke-box is given a coned shape (taper 1 : 2 to 1 : 1·5) in order to reduce the resistance of the air in front.

20. *Steam dome.* — The most recent locomotives of all the administrations have one steam dome, in a number of cases also two steam domes which are connected together. Many of the administrations fit the inside of the dome with special deflector plates and screen plates or hoods and screens for separating the water; moreover on some of the locomotives, for instance goods locomotives of the Saxon State Railway, trials have recently begun with steam driers and water separators, of different kinds.

The locomotives of the Oldenburg State Railway formerly did not have steam domes at all; now they are also fitted with such domes.

21. *Boiler lagging.* — Different kinds of asbestos are used for lagging; the asbestos is sewn together so as to form cloth about 25 millimetres (1 inch) thick. This is placed either direct on the boiler plate, or fixed under the sheet-iron cover, which is about 2 millimetres ($^5/_{64}$ inch) thick, by means of hoop iron; in some cases, it is also fixed to special iron rings which are permanently connected with the sheet-iron cover. Some of the railways only apply blue-asbestos lagging to that part of the boiler which projects into the cab, so as to protect the locomotive crews against the radiant heat. The Wurtemberg State Railway, the Dutch State Railway, and the Dutch Railway Company use impregnated felt, while other administrations complain that this material readily becomes destroyed. Wood lagging has also been tried, but is unsatisfactory because it has a short life and does not give sufficient protection against the heat.

The Baden State Railway carried out

experiments in order to determine the efficiency of different kinds of lagging; the results obtained are recorded in the *Organ für die Fortschritte des Eisenbahnwesens*, 1906, page 6. The Danish State Railway, in order to determine the difference in the heat radiation of a lagged boiler and an unlagged boiler, placed on each of two similar boilers a sheet-metal vessel containing 3 litres (0·660 English gallon) of water, the bottom of the vessel being shaped to fit the curved boiler surface exactly. The rise of temperature in the water of the vessels then enabled the number of heat units to be measured, which passed every ten minutes through the boiler surface. The locomotives were standing still in the open, and during the experiments there was the same pressure in both. The results obtained showed that the additional cost of the lagging and of putting it on was regained in three years by the saving in coal.

The results generally obtained show that there is a reduction in the radiation and consequently a sufficient reduction of the temperature in the cab, but no measurements of the more accurate kind have been made.

22. *Systems of thermal storage.* — No system of thermal storage in the boilers is used.

23. *Mechanical stoking.* — The Baden State Railway has quite recently been using locomotives with extra firing by means of petroleum residues, in order to reduce the amount of smoke in sections where there are many tunnels. The arrangement is the same as that used on the Arlberg lines of the Austrian State Railway.

On two small tank locomotives of the Bavarian State Railway, which are run each by one single man, the coal space is arranged so as to form a charging cone, which is above the back wall of the boiler. The coal (Bohemian nut-coal) falls through the opening at the bottom of the cone direct on to the grate. The opening forms a grate with a sliding door; the slide is set by the driver as may be required. Below the cone there are openings, which allow the driver to observe the fire and to use the firing tools. This arrangement has given good results, but is only suitable for simple traffic conditions.

The Swedish State Railway made some trials with mechanical stokers on locomotives which burnt peat, but no useful results were obtained. No other trials are reported.

Appendix to question VI-A.

1° The answers sent by the Norwegian State Railway in reply to question VI-*A* could not be utilized in the body of the report as they arrived too late; a summary is therefore given in this appendix.

The Norwegian State Railway chiefly uses round-topped fire-boxes, but also has some locomotives with Belpaire boilers.

In all the newer boilers the roof stays are arranged radially.

There are some locomotives of American origin with steel fire-boxes; all the other have copper fire-boxes. The former have given nearly as good results as the latter, but greater care is necessary in the firing, and the washing out must be done very carefully, as the steel tube-plates are very sensitive to sudden and strong cooling.

The joint between the back plate and the

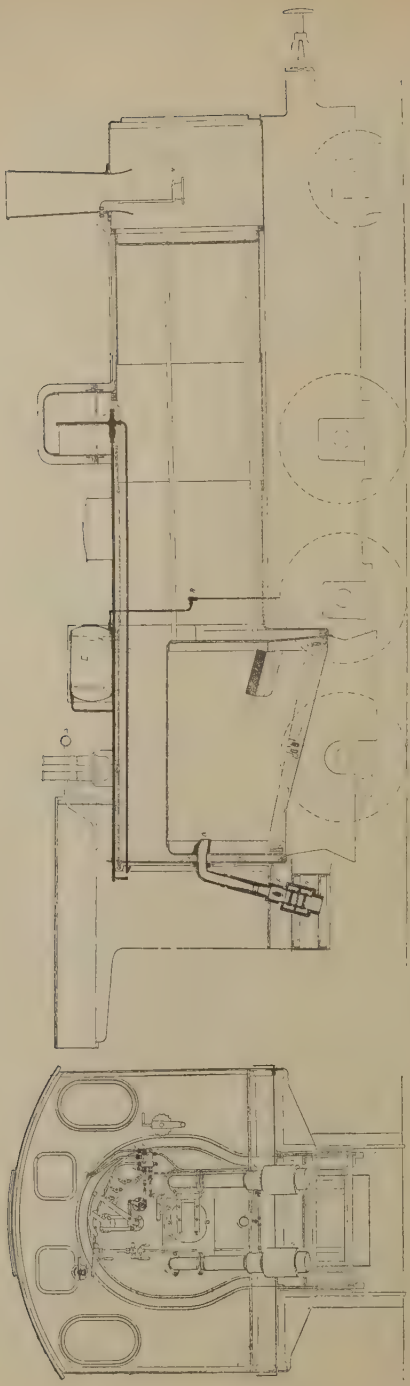


Fig. 44. — Arrangement of the Staby smoke-consumer on locomotives of the Prussian-Hessian State Railway.

inner fire-box plate, for the fire-door, is of the Webb type.

The ratio of the total grate area to useful grate area varies between the narrow limits of $R : R_f = 1 : 0{\cdot}353$ to $1 : 0{\cdot}361$; and that of total grate area to total tube, between $R : H_R = 1 : 56{\cdot}1$ to $1 : 57{\cdot}3$.

Wrought-iron tubes are fixed in the tube-plates by means of the ordinary roller expander; Serve tubes are not used.

The steel tubes have shown a tendency to corrosion, while the wrought-iron tubes behave materially better.

Copper tubes, which are not liable to corrosion, are still in use on older locomotives.

Galvanized iron tubes are not used. Iron tubes with copper sleeves are only regarded as a makeshift, particularly in cases where it is difficult to get the iron tubes tight. These copper sleeves have a length of 100 to 150 millimetres ($3\ ^{15}/_{16}$ to $5\ ^{29}/_{32}$ inches) in the more recent cases and are brazed on. They have given good results in every way.

Ferrules are used in order to protect the tube ends in the fire-box against being burnt, and in order to make tight joints when there are leaks. They are 3 millimetres ($^1/_8$ inch) thick and have a taper varying from 1 : 20 to 1 : 30.

At the fire-box ends the tubes are beaded over; at the smoke box ends only occasionally.

The tubes are arranged in vertical rows in order to allow the water to circulate more freely.

The highest working pressure on the more recent locomotives is 13 kilograms per square centimetre (185 lb. per square inch); there are a few smaller boilers, of narrow-gauge locomotives, which work at

14 kilograms per square centimetre (199 lb. per square inch). Special means for keeping the tubes tight and the tube-plates in good condition are not necessary.

Hammering the tube-plates has not been tried.

All locomotives are fitted with spark arresters; they also all have domes.

Formerly, the locomotives were lagged with felt and wood, but now asbestos lagging and magnesia sectional lagging are more frequently used.

2. A new arrangement of the Staby smoke-consuming device, as now used on the German railways, is shown in figure 44 and inserted here.

Final conclusions on subject VI, littera A.

(*Germany, Denmark, Luxemburg, Niederland, Norway, Sweden, Switserland.*)

Belpaire boilers are used occasionally, boilers with superelevated fire-box roof only exceptionally. The design preferred is that in which the barrel extends into the fire-box, the fire-box shell just having the same diameter as the last ring of the boiler. Cylindrical fire-boxes, in so far as they have been tried, have not given satisfactory results, and special combustion chambers have not been used. Wide fire boxes, extending beyond the frame plates, are still in the experimental stage.

Radial roof stays have given satisfactory results and they, as well as stays arranged vertically, are often used. Roof bars as the sole means of stiffening the top of the fire-boxes are no longer to be found on the more recent locomotives. Short roof bars instead of the two or three front rows of roof stays are nearly always used, specially arranged so as to allow for the mobility of the front top part of the fire-box.

The most suitable material for fire-boxes is generally recognized to be copper, obtained either by smelting or electrolytically. Special alloys, for instance nickel copper, are being tried. Ingot-iron fire-boxes have as yet given unsatisfactory results.

Fire-doors are generally in the form of single swing doors, less frequently in that of sliding doors in two parts. In the case of wide boilers, double swing doors have been introduced, and also drop doors in three parts, opening inwards. Devices for an over-grate supply of air are generally provided and in many cases developed into real smoke-consuming appliances.

The joints at the fire-hole are generally made with rings of rectangular section, the thickness of which has lately been materially reduced; Webb's dished joint is also used. Both designs have given good results. Simple riveting suffices in both cases.

The ratio of total grate area to useful grate area, $R : R_f$, shows that the latter is being increased, as the former average of 1 : 0·45 is in many cases exceeded.

The ratio of total grate area to total heating surface, $R : H_R$, is also altered in favour of the latter and illustrates the tendency to utilize the quantity of heat produced on the grate, in so far as it is still possible to do so profitably in practice.

Movable grates have as yet had comparatively little attention devoted to them. In so far as they are used, this is to facilitate the cleaning of the fires after the locomotive has been used. Cleaning the grates while running is less frequently the

object aimed at, but it might be advisable to pay greater attention to this in the future in the case of locomotives which have to do heavy and long runs.

Ingot iron is generally pronounced to be the most suitable material for smoke tubes; in a few cases mild steel is named. Copper is only used exceptionally for this purpose, and brass not at all.

Serve tubes are generally condemned; the Alsace-Lorraine Railway forms the sole exception.

The careful purification of the feed-water *before* it is put into the boiler is the chief means recommended for preventing the production of defects in the smoke tubes and tube-plates.

Copper sleeves to the smoke tubes at the fire-box ends are not approved by the majority of the administrations; only the south German and Swiss railways consider them useful and state that good results are obtained.

Ferrules are only considered of practical value in a few cases, especially when cooper sleeves are used. The system of placing copper liners round the outside of the tube ends, or of brazing them on, seems to give good results.

Several administrations have found the cold hammering of the copper plates used for the fire-boxes to give good results.

Extended smoke-boxes are much used and are considered advantageous.

Steam domes are used everywhere.

Blue asbestos and white asbestos are preferred for lagging and are found to give good results.

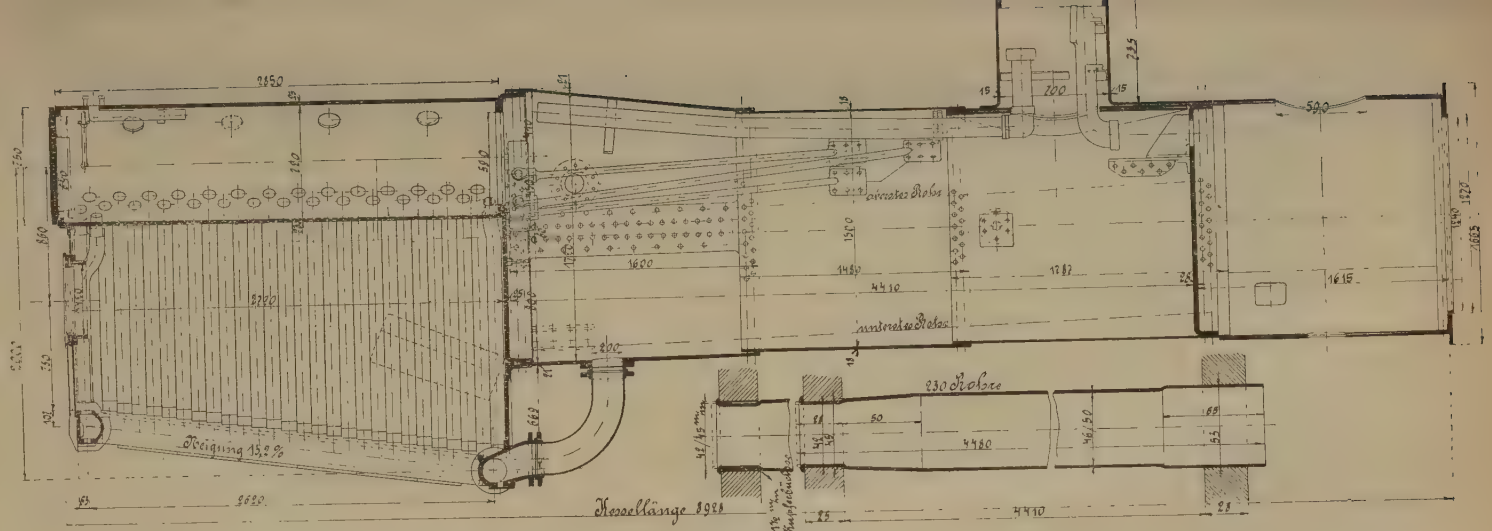
Mechanical stoking is not used in the case of any of the larger boilers.

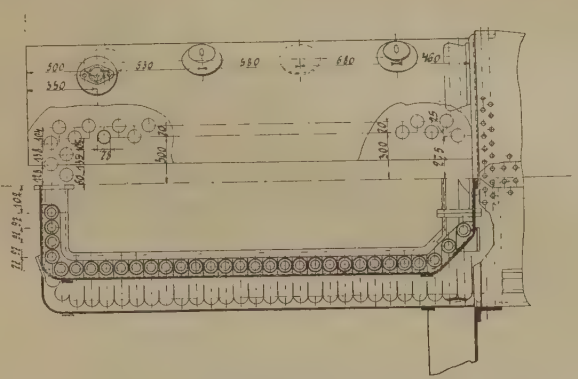
Working pressures exceeding 12·65 kilograms per square centimetre (180 lb. per square inch) are used nearly everywhere, on express and passenger saturated-steam locomotives; on goods locomotives, the working pressure seldom exceeds 12 kilograms per square centimetre (171 lb. per square inch). Superheated-steam twin locomotives work at pressures of 12 kilograms per square centimetre (171 lb. per square inch); superheated-steam compound locomotives work at pressures of from 13 to 16 kilograms per square centimetre (185 to 228 lb. per square inch).

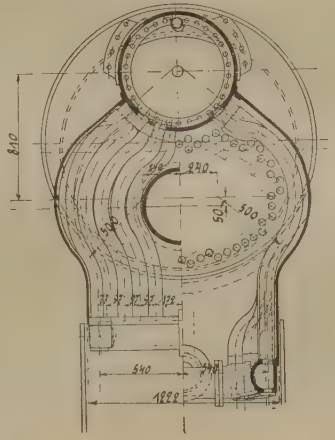
B. — Boilers with water tubes. Superheaters. Valve gear for superheated steam. Feed-water heaters.

A. — Boilers with water tubes.

1. *Water-tube boilers.* — Water-tube boilers are not in use. On the other hand two locomotives on the Prussian-Hessian State Railway, one on the Swedish State Railway, and two on the Swiss Federal Railway, have now for a short time been in use, which are equipped with water-tube fire-boxes, so-called Brotan boilers. The Prussian State boilers have not satisfied expectations in the two years in which they have been in use, as the water tubes in the fire zone suffered material deformation and wear. This disadvantage is to be counteracted by adding firebrick walls.







Weight, empty	58·6 tons	(57·7 English tons).
— in running order	65·1 —	(64·1 — —).
— adhesive	45·7 —	(45·0 — —).
Working pressure	15·0 atmospheres.	
Test pressure	20·0 —	
Heating surface, water-tube fire-box	16·2 sq. metres	(174·38 sq. ft.).
Heating surface, smoke-tube	159·0 —	(1,711·52 —).
Heating surface, bottom of collector	1·84 —	(19·80 —).
Heating surface, total	177·04 —	(1,905·70 —).
Grate area, total	2·5 —	(26·91 —).
— — useful	1·3 —	(13·99 —).
Water space in boiler, with water-level 50 millimetres (2 inches) below top of collector	6·1 cub. metres	(215·43 cub. ft.).
Steam space, with water-level 50 millimetres (2 inches) below top of collector	2·2 —	(77·69 —).

Diameter of cylinders : 360 and 570 millimetres (1 ft. 2 5/32 in. and 1 ft. 10 7/10 in.).
Length of stroke . . . . . 660 millimetres (2 ft. 2 in.).
Diameter of driving wheels . . . . . 1,780 — (5 ft. 10 in.).

Fig. 45. — Boiler for 3/5 four-cylinder compound express locomotives with water-tube fire-box (Brotan boiler), Swiss Federal Railway.

Explanation of German terms : Oberstes Rohr = Highest tubes. — Unterstes Rohr = Lowest tube. — Rohre = Tubes. — Neigung = Inclination. — Kessellänge = Length of boiler. **Kupferbüchse = Copper lining.**

The Swiss and the Swedish trials have not yet led to any results. The boiler with water-tube fire-box used on the $^3/_5$ express locomotive of the Swiss Federal Railway is shown in figure 45.

In this design, the side walls and the back of the fire-box are formed by bent steel tubes, placed close together, which are fixed at the bottom to a foundation tube, which is in place of the ordinary foundation ring or mud ring; at the top, they end in a small longitudinal steam drum having an internal diameter of 720 millimetres (2 ft. $^{11}/_{32}$ in.), the bottom part of which is at the same time utilized as a direct heating surface (1·84 square metres [19·80 square feet]). This drum joins on to the barrel, the back ring of which is conical; the back of this ring together with the top of the drum is about 180 or 120 millimetres (7 $^3/_{32}$ or 4 $^{23}/_{32}$ in.) higher than the top of the barrel; the latter has an internal diameter of 1,500 millimetres (4 ft. 11 in.). The connection between the drum and the barrel is circular and has a diameter of 590 millimetres (1 ft. 11 $^1/_4$ in.), and the steam is taken by collecting tubes from the front of the drum to the dome. The connection between the foundation tube and the barrel consists of only one tube having an internal diameter of 200 millimetres (7 $^7/_8$ inches) which ends centrally at the bottom of the last ring at a distance of about 620 millimetres (2 ft. $^3/_8$ in.) from the tube-plate. The long upper drum placed above the barrel, usual with Brotan boilers, is absent in this case.

The front wall of the fire-box is formed by a circular tube-plate; in the lower part of this, the 230 smoke tubes are inserted, and at the top there is the opening having a clear diameter of 590 millimetres (1 ft. 11 $^1/_4$ in.) for the connexion. The plate at the same time closes the back of the barrel and has a flange which is inserted in the back ring of the barrel and riveted to it. This tube-plate has a diameter of 1,720 millimetres (5 ft. 7 $^{23}/_{32}$ in.) and is 25 millimetres (1 inch) thick. Above the smoke tubes, on both sides of the connecting opening, there are strong stays extending to the middle ring of the barrel.

Below the tube-plate and outside the water tubes, the water-tube fire-box is surrounded, up to the drum, with plate 15 or 10 millimetres ($^{19}/_{32}$ or $^{25}/_{64}$ inch) thick.

Otherwise the fire-box has the usual arrangement of grate, brick arch and Langer-Marcotty smoke consumer; it is intended to work at a pressure of 15 atmospheres.

2. *Water tubes in the fire-boxes.* — Special systems of water tubes in the fire-boxes are not used.

3. *Drawings of water-tubes.* — No such drawings are available, except that reproduced in figure 45.

4. *Analyses of smoke-box gases of water-tube boilers.* — No such analyses have been made.

B. — Steam superheaters and valve gear for superheated-steam.

By far the greater number of all the superheated-steam locomotives in use is to be found on the Prussian-Hessian State Railway; the results obtained there are accordingly considered in some detail below.

1. *Use of superheated steam.* — Superheated-steam locomotives are used, among

the railways with which we are concerned, by the Prussian-Hessian State Railway, the Baden State Railway, the Bavarian State Railway, the Saxon State Railway, the Wurtemberg State Railway, the Swedish State Railway, the Dutch Railway Company, the Swiss Federal Railway the St. Gothard Railway, the Rhetian Railway, and the Stockholm-Rimbö Railway. The Alsace-Lorraine has only one such locomotive in use, of older design, but is having eight built; the Norwegian State Railway is having two delivered in the middle of 1909; the Danish State Railway has ten in order, and the Luxemburg Prinz-Heinrich Railway intends to make a trial of one shortly. The Oldenburg State Railway and the Dutch State Railway do not use superheated-steam locomotives, and have no intention of building any.

The systems used are :

a) The Schmidt smoke-box superheater;

b) The Schmidt smoke-tube superheater;

c) The Pielock superheater;

d) The Clench-Gölsdorf superheater.

A full description of these superheaters and all their details is to be found in the work *Die Dampflokomotiven der Gegenwart*, by Robert Garbe, Berlin 1907, and in the paper by Robert Garbe, entitled, " The application of highly-superheated steam to locomotives ", published in the *Bulletin of the Railway Congress*, 1908, May, page 517; from these short extracts are made for the following sections *a*), *b*) and *c*), while the description of the Clench-Gölsdorf superheater is based on information supplied by the Baden State Railway.

a) *Description of the smoke-box superheater.*

(See fig. 46 to 48.)

The superheater placed in the smoke-box consists of 3 rows of 20 tubes each having a diameter of $\frac{41{\cdot}5 \text{ mill.}}{33{\cdot}5 \text{ mill.}} \frac{(1\ 41/64 \text{ in.})}{(1\ 21/64 \text{ in.})}$ or $\frac{44{\cdot}5 \text{ mill.}}{35{\cdot}5 \text{ mill.}} \frac{(1\ 3/4 \text{ in.})}{(1\ 13/32 \text{ in.})}$; the hot gases reach them through a flue tube having a clear diameter of 280 to 305 millimetres (11 inches to 1 foot) placed between the smoke tubes at the lower part of the barrel. The tubes are bent to correspond to the walls of the smoke-box, forming substantially three consecutive rings. These sets of rings are placed one behind the other at short intervals. The ends which are bent upwards are expanded into the bottoms of two long steam collectors, made of steel castings, which are placed in the smoke-box, the one to the right and the other to the left of the chimney. All the tubes of the inner rings are bent away at the bottom from the two outer sets of rings, so that there is a space between the inner and the two outer sets of rings (superheater fire-box) which the hot gases coming through the flue tube enter in the first instance. The shell enclosing the sets of tubes is shaped to the form of the inner tube rings and extends, on the right and on the left side of the smoke-box, up to above the height of the blast pipe, so that the whole superheater, up to near the tube ends, which are expanded into the bottom of the steam collectors, is enclosed in an iron case. This can be closed up above on both sides of the smoke-box by narrow damper flaps, which can be operated from the cab.

The live steam passes in the first place

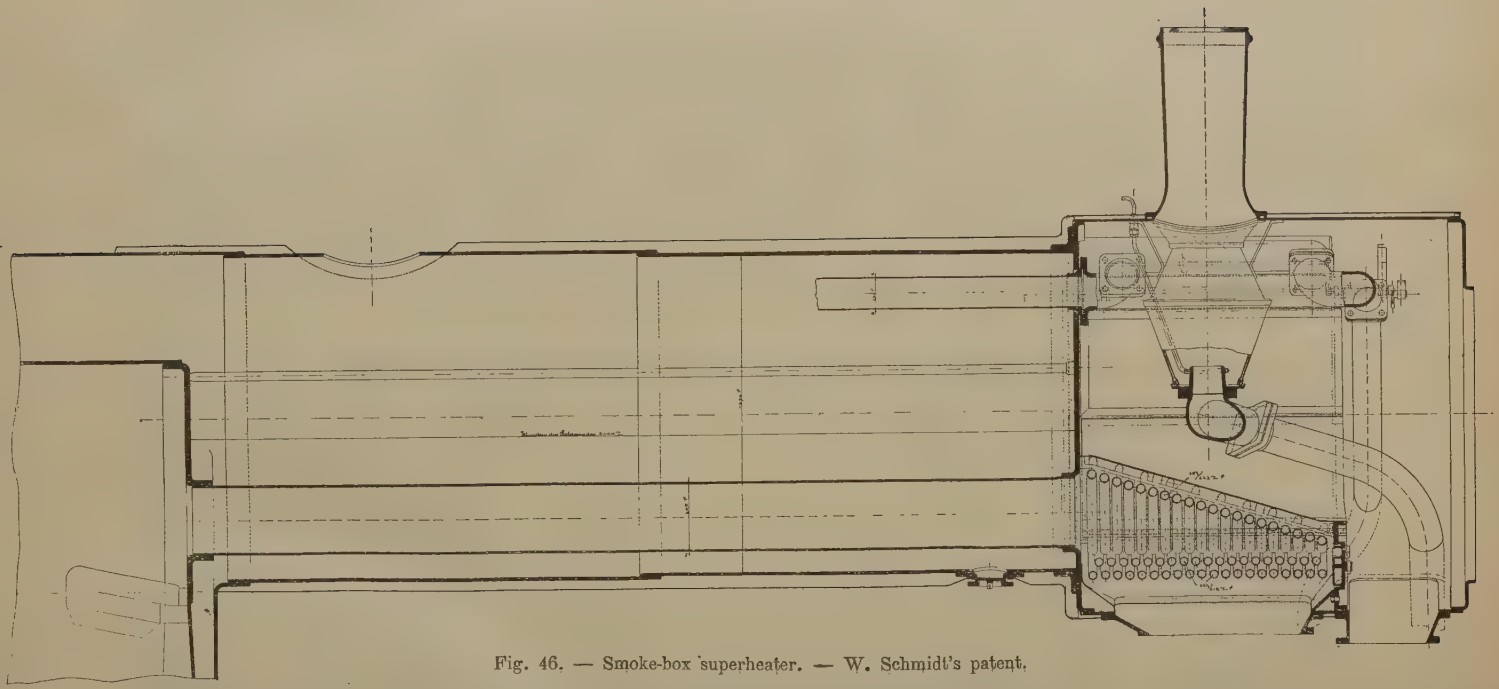


Fig. 46. — Smoke-box superheater. — W. Schmidt's patent.

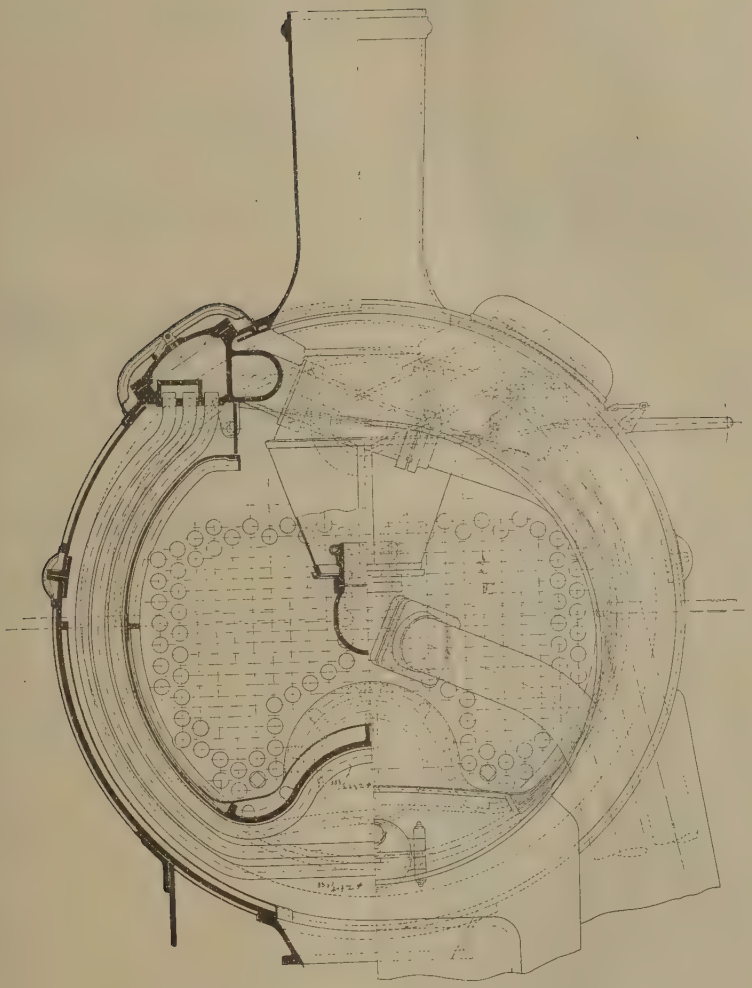
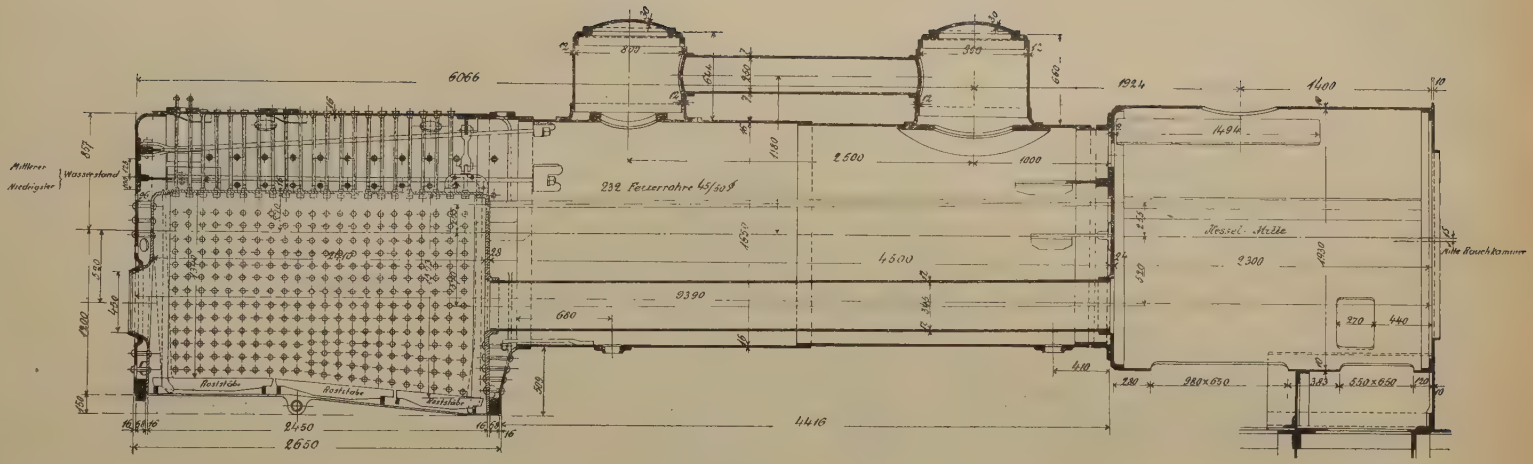
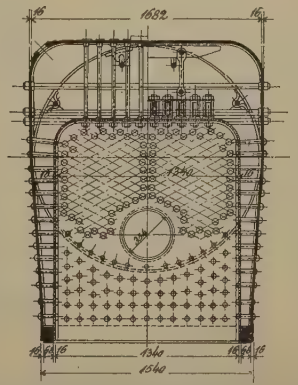


Fig. 47. — Smoke-box superheater. — W. Schmidt's patent.

from the boiler to the right collector and then through the inner set of tubes to the left collector. An internal partition, which cuts off the two inner sets of tubes, then compels the steam to pass through the middle set of tubes again to the right collector. In this there is also an internal partition, which then compels the steam





Working pressure	12 atmospheres.		
Test pressure	13	—	
Heating surface, tubes	147·61 sq. metres	(1,588·91 sq. feet).	
— — fire-box	13·09 —	—	(140·90 — —).
— — total.	165·58 —	—	(1,782·35 — —).
Grate area	3·29 —	—	(35·41 — —).
Heating surface, flue tube	4·88 —	—	(52·52 — —).

Cylinders, diameter : 590 × 860 millim. (1 ft. 11 1/4 in. × 2 ft. 2 18/10 in.).	
Length of stroke	630 millim. (2 ft. 13/10 in.).
Driving wheels, diameter	1,240 millim. (4 ft. 18/10 in.).
Weight, empty	62.5 tons (61·51 Engl. tons).
Weight, in running order	70·4 tons (69·28 Engl. tons).
Weight, adhesive	70·4 tons (69·28 Engl. tons).

Fig. 48. — Boiler for 5/5 two-cylinder superheated-steam locomotive for goods trains. — Saxon State Railway.

Explanation of Germans terms : 232 Feuerrohre 45/60 = 232 smoke tubes 45 × 60 millimetres (1 25/32 × 2 3/8 inches). — Roststäbe = Grate bars. — Mittlerer Wasserstand = Average water-level. Niedrigster Wasserstand = Lowest water-level. — Kessel-Mitte = Centre line of barrel. — Mitte Rauchkammer = Centre line of smoke-box.

to pass through the outer set of tubes again to the left collector, from which it passes in a highly-superheated condition to the valve chest. Thus the steam changes its direction three times while passing through the superheater, and that in such a way that the hot gases both when entering and when leaving come into contact with surfaces which are cooled by wet steam, while the surfaces in contact with superheated steam, which are therefore much hotter, are in a sufficiently-protected position. The high temperature of the gases can therefore not become dangerous to the walls of the superheater tubes, and yet the gases become cooled considerably, because they must pass, at their exit, between the coldest tubes.

The collectors have covers which are conveniently accessible from outside; when these are taken off, the tube ends can readily be expanded again or plugged if necessary. The soot which collects is blown away, from time to time, by compressed air or steam; a valve is provided for the purpose, which can be operated from the cab. This supplies compressed air or dry steam from the dome to two pipes with small holes, which are placed on the walls of the smoke-box transversely to the superheater tubes. The separate jets of steam are directed upwards and downwards, pass between the superheater and sweep them clean. The whole arrangement only requires the diameter of the smoke-box to be increased a small amount (1).

(1) See Robert Garbe, *Die Dampflokomotiven der Gegenwart*, pp. 279 and seq.

b) *Description of the smoke tube superheater.*

(See figs. 49 to 54.)

The boiler for the smoke-tube superheater has in its upper part three or four (in smaller boilers also only two) rows of larger smoke tubes; each of these tubes holds a superheater element consisting of two U tubes, which are connected by a bend in the smoke-box so as to form one continuous tube. Thus the steam passes twice forwards and backwards in the superheater element of each smoke tube. The two ends of each superheater element are bent upwards and expanded into one common strong flange; this is fixed to the steam collector by a strong screw which is in the middle between the two openings in the steam collector, on a vertical flange and by means of horizontal studs.

This design, which makes it necessary to have the superheater tubes bent backwards, so as to give greater accessibility, has it is true the disadvantage that the smoke-box must be a little longer, so that there may be enough room available for the damper flaps behind the spark arrester, but it probably ensures a good utilization of the hot gases and has consequently been used till now on the Prussian superheated-steam locomotives. With this design, the steam is superheated to 360° C. (680° Fahr.); this is the same temperature as is attained with a smoke-box superheater having the same heating surface.

The hot gases flow in part through the lower smoke tubes into the smoke-box, in part through the large upper smoke tubes; and in doing so give up part of their heat to the boiler water surrounding these tubes, but the greater part to the super-

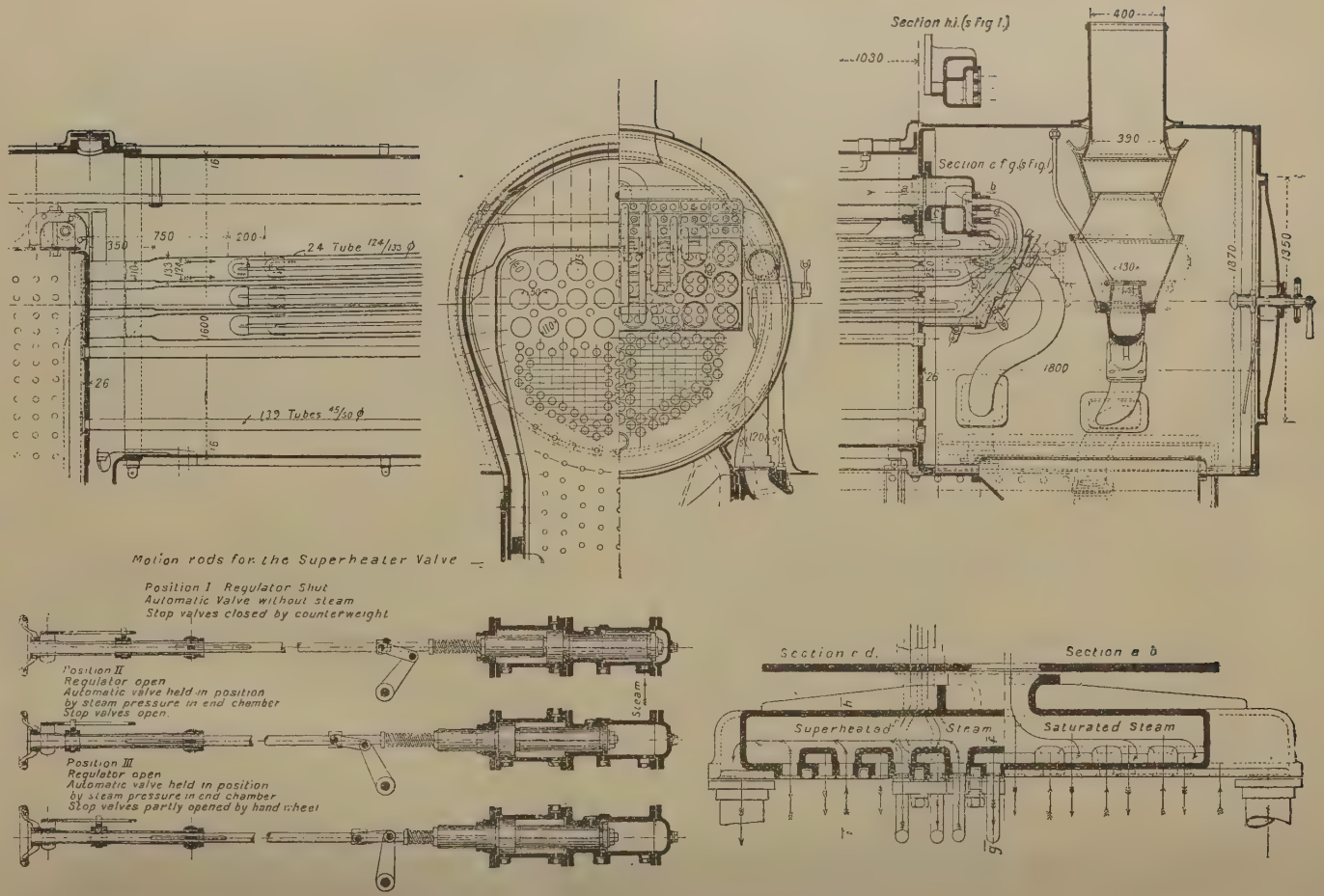


Fig. 49. — The Schmidt superheater for locomotives.

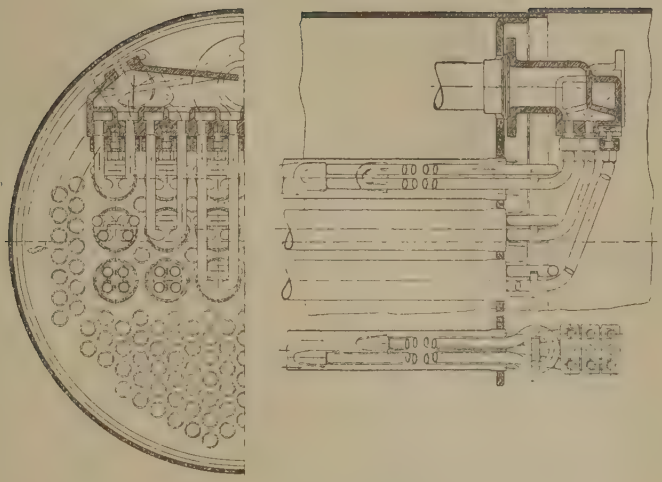


Fig. 50. — The Schmidt superheater for locomotives.

heater tubes which are inside the other tubes. The passage of the gases through the large smoke tubes is regulated by damper flaps in the smoke-box, which are kept open by the pressure of the steam as long as the regulator is open; when the regulator is closed they are automatically closed by a counterweight or by a spring. When the locomotive is standing still or running with regulator closed the gases accordingly do not flow through the smoke tubes and consequently the superheater tubes, which are now not cooled by the passage of steam, are not heated. The overheating of the superheater tubes is in this way effectively prevented. The damper flaps can also be operated, while running with regulator open, by means of a handwheel placed in the cab, and wholly or partly closed or opened. The three chief positions of the damper flaps are :

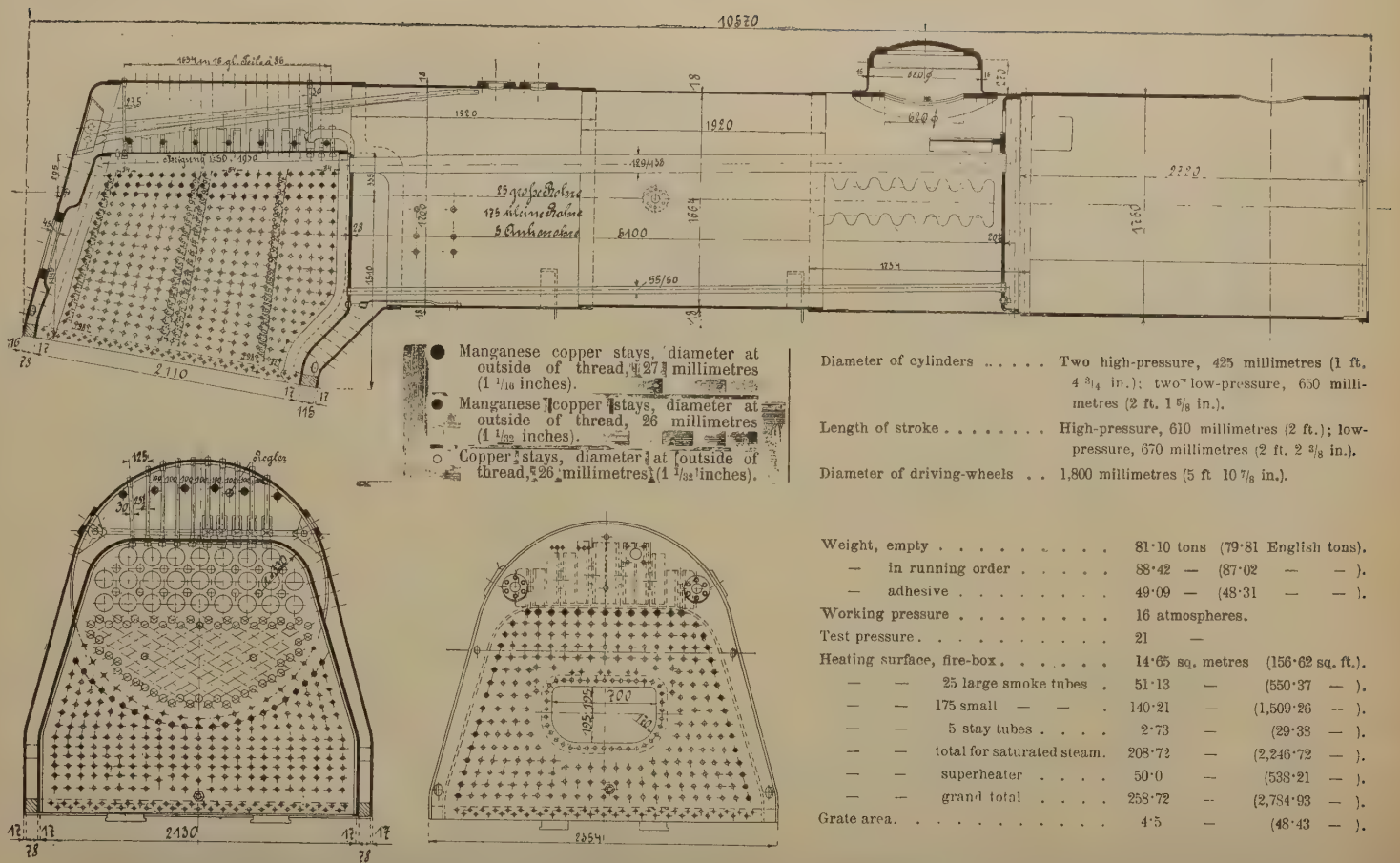
Position 1 : Regulator closed. The automatic valve is without steam. The dampers are closed by the counterweight.

Position 2 : Regulator open. The piston of the automatic valve is kept in its extreme position by the steam pressure The dampers are open to their limit.

Position 3 : Regulator open. The piston of the automatic valve is kept in its extreme position by the steam pressure. The dampers can however, by means of the handwheel, be closed partly or fully.

In this way the steam production and the superheat can be regulated. If the dampers are partly closed so as to reduce the draft through the large smoke tubes, the degree of superheat is reduced; in consequence of the throttling a correspondingly-larger proportion of the hot gases passes through the lower smoke tubes and the steam production is increased.

The automatic gear which regulates the

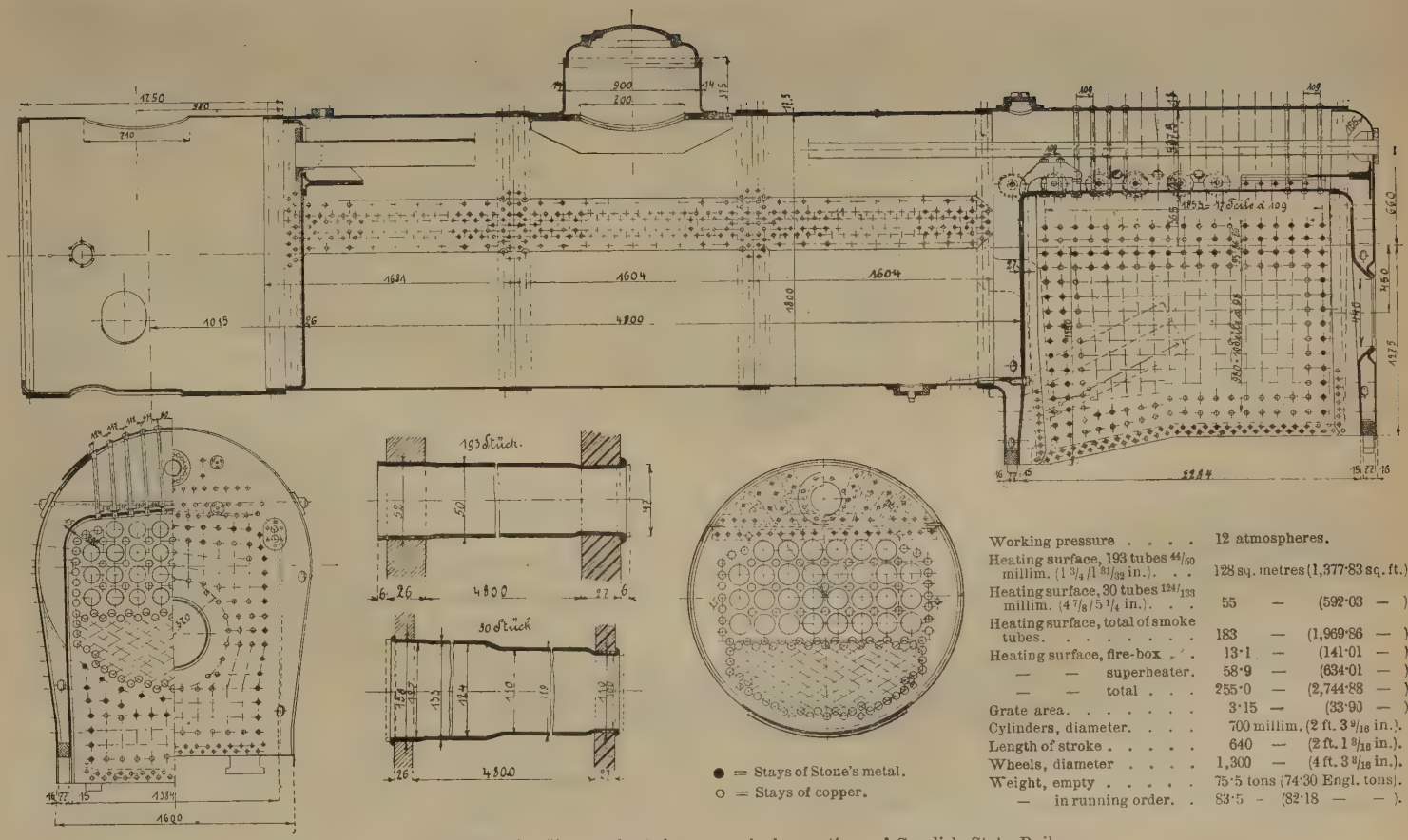


Diameter of cylinders	Two high-pressure, 425 millimetres (1 ft. 4 3/4 in.); two low-pressure, 650 millimetres (2 ft. 1 5/8 in.).
Length of stroke	High-pressure, 610 millimetres (2 ft.); low-pressure, 670 millimetres (2 ft. 2 3/8 in.).
Diameter of driving-wheels . .	1,800 millimetres (5 ft 10 7/8 in.).

Weight, empty	81·10 tons	(79·81 English tons).	
— in running order	88·42 —	(87·02 —	—).
— adhesive	49·09 —	(48·31 —	—).
Working pressure	16 atmospheres.		
Test pressure	21 —		
Heating surface, fire-box	14·65 sq. metres	(156·62 sq. ft.).	
— — 25 large smoke tubes .	51·13 —	(550·37 —	).
— — 175 small — — .	140·21 —	(1,509·26 —	).
— — 5 stay tubes	2·73 —	(29·39 —	).
— — total for saturated steam.	208·72 —	(2,246·72 —	).
— — superheater	50·0 —	(538·21 —	).
— — grand total	258·72 —	(2,784·93 —	).
Grate area.	4·5 —	(48·43 —	).

Fig. 51. — Schmidt smoke-tube superheater. Boiler for 3/6 express-locomotive. Baden State Railway. Four-cylinder compound.

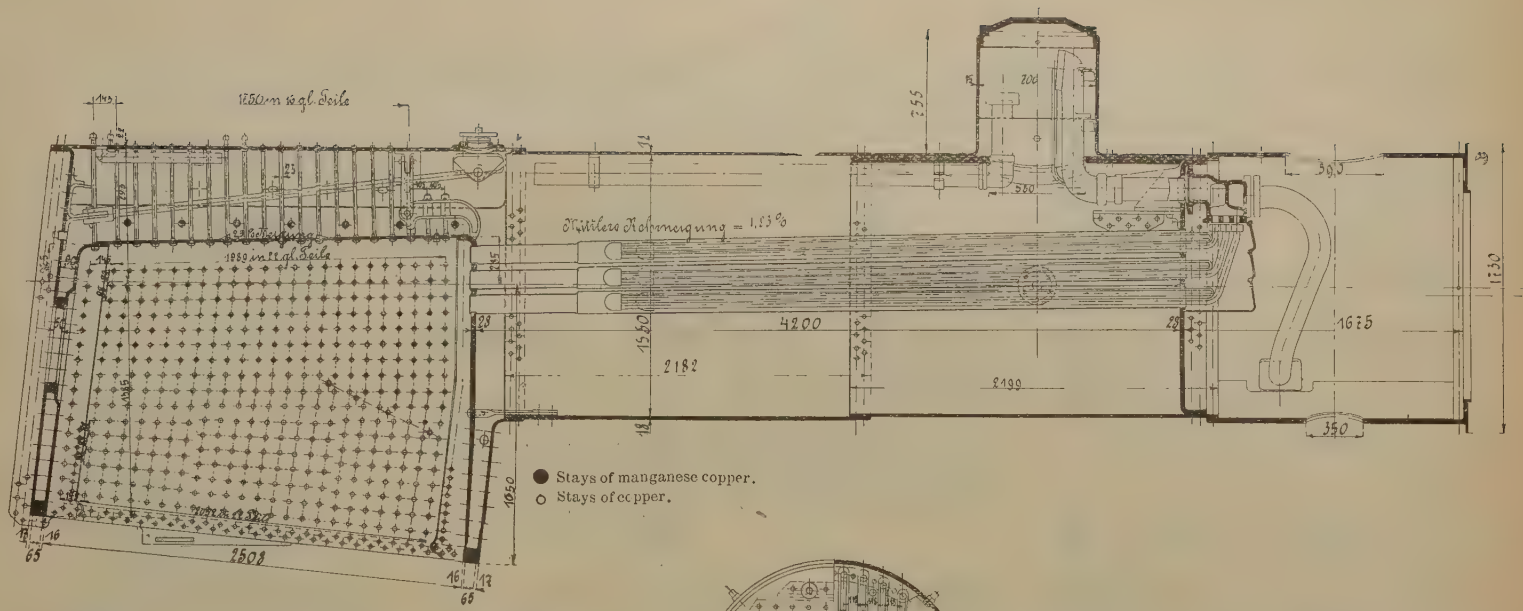
Explanation of German terms : 1,634 in 19 gl. Teile à 36 = 1,634 into 19 equal parts of 86 each. — Neigung = Inclination. — grosse Rohre = large tubes. — kleine Rohre = small tubes. Ankerrohre = stay tubes. — Regler = Regulator.

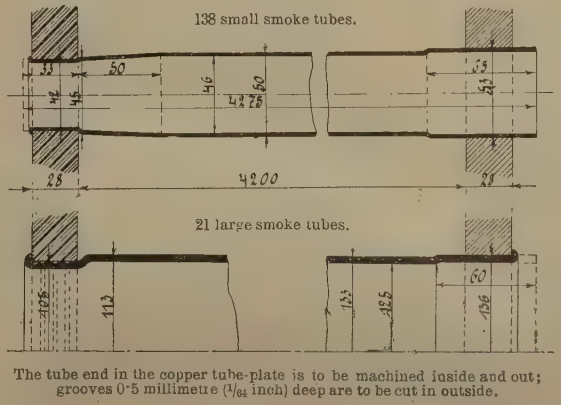


Working pressure	12 atmospheres.		
Heating surface, 193 tubes $^{44}/_{50}$ millim. (1 $^{3}/_{4}$/1 $^{31}/_{32}$ in.). . .	128 sq. metres	(1,377·83 sq. ft.).	
Heating surface, 30 tubes $^{124}/_{133}$ millim. (4 $^{7}/_{8}$/5 $^{1}/_{4}$ in.). . .	55	—	(592·03 —).
Heating surface, total of smoke tubes.	183	—	(1,969·86 —).
Heating surface, fire-box . . .	13·1	—	(141·01 —).
— — superheater.	58·9	—	(634·01 —).
— — total . . .	255·0	—	(2,744·88 —).
Grate area.	3·15	—	(33·90 —).
Cylinders, diameter. . . .	700 millim.	(2 ft. 3 $^{9}/_{16}$ in.).	
Length of stroke	640	—	(2 ft. 1 $^{3}/_{16}$ in.).
Wheels, diameter	1,300	—	(4 ft. 3 $^{3}/_{16}$ in.).
Weight, empty	75·5 tons	(74·30 Engl. tons).	
— in running order. .	83·5 -	(82·18 —	—).

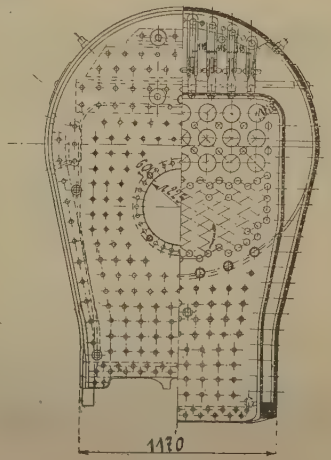
Fig. 52. — Boiler for $^{5}/_{5}$ superheated-steam swin locomotives of Swedish State Railway.

Explanation of German terms : 1,853 = 17 Teile à 109 = 1,853 = 17 parts of 109 each. — 980 = 10 Teile à 98 = 980 = 10 parts of 98 each. — 193 Stück = 193 tubes. — 30 Stück = 30 tubes.



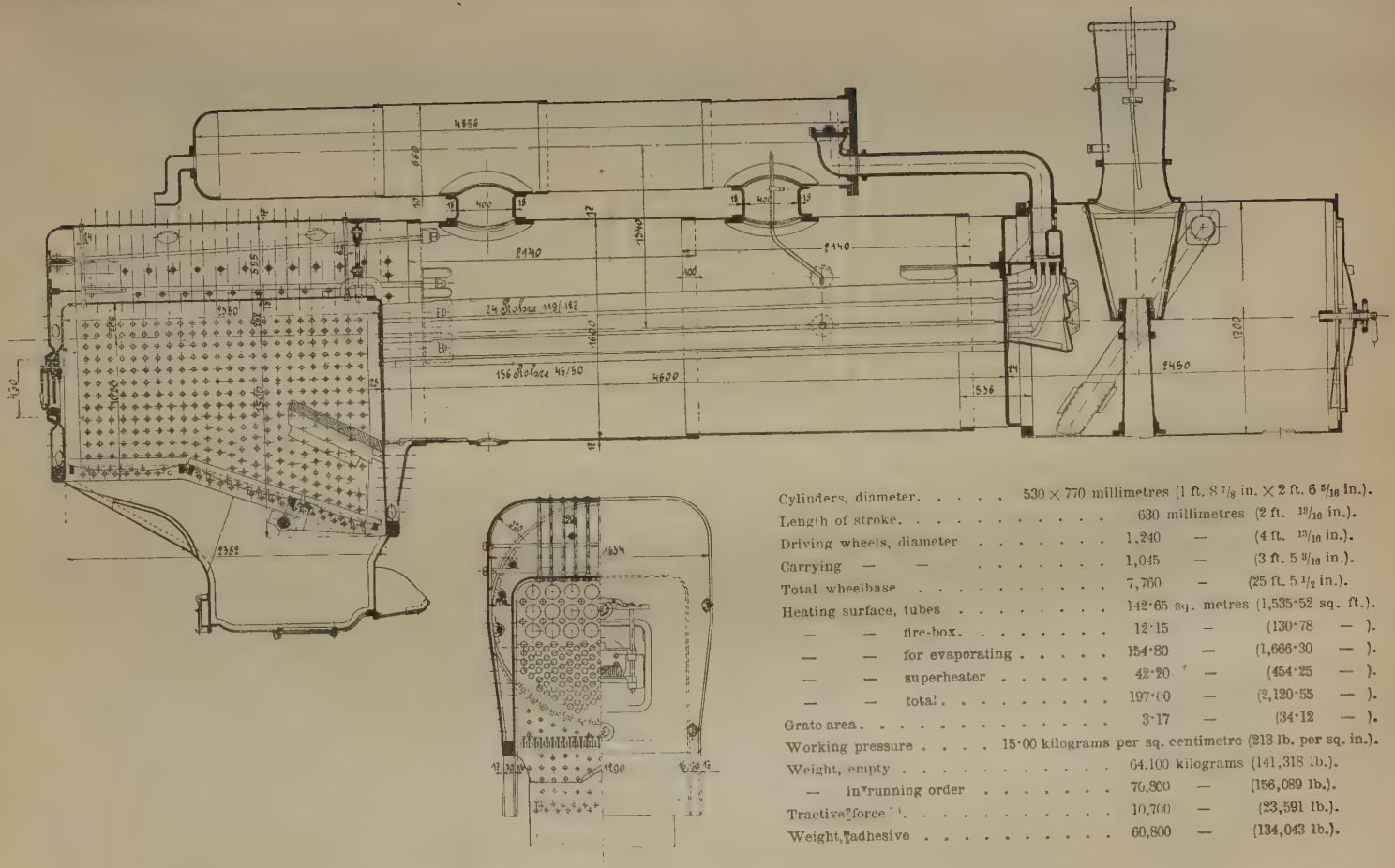


The tube end in the copper tube-plate is to be machined inside and out; grooves 0·5 millimetre ($^1/_{64}$ inch) deep are to be cut in outside.



Working pressure	12 atmospheres.	
Heating surface, fire-box	14·2 sq. metres	(152·85 sq. ft.).
— — smoke tubes	126·8 —	(1,364·92 —).
— — superheater	37·6 —	(404·73 —).
— — total	178·6 —	(1,922·51 —).
Grate area, useful	1·1 —	(11·84 —).
— — total	2·44 —	(26·26 —).
Water space, with water-level 50 millimetres (1 $^{31}/_{32}$ inches) above fire-box	5·5 cub. metres	(194·24 cub. ft.)
Steam space, with water level 50 millimetres (1 $^{31}/_{32}$ inches) above fire-box	2·2 — —	(77·63 —).
Cylinders, diameter	570 millim.	(1 ft. 10 $^7/_{16}$ in.).
Length of shoke	640 —	(2 ft. 1 $^3/_{16}$ in.).
Driving wheels, diameter	1,330 —	(4 ft. 4 $^3/_8$ in.).
Weight, empty	60·4 tons	(59·44 Engl. tons).
— in running order	67·1 —	(66·04 — —).
— adhesive	58·0 —	(57·08 — —).

Fig. 52. — Boiler for 4/- superheated steam twin locomotives for goods train. Swiss Federal Railways.



Cylinders, diameter	530 × 770 millimetres	(1 ft. 8 7/8 in. × 2 ft. 6 5/16 in.).	
Length of stroke	630 millimetres	(2 ft. 18/16 in.).	
Driving wheels, diameter	1,240 —	(4 ft. 13/16 in.).	
Carrying — —	1,045 —	(3 ft. 5 3/16 in.).	
Total wheelbase	7,760 —	(25 ft. 5 1/2 in.).	
Heating surface, tubes	142·65 sq. metres	(1,535·52 sq. ft.).	
— — fire-box	12·15 —	(130·78 —).	
— — for evaporating	154·80 —	(1,666·30 —).	
— — superheater	42·20 —	(454·25 —).	
— — total	197·00 —	(2,120·55 —).	
Grate area	3·17 —	(34·12 —).	
Working pressure	15·00 kilograms per sq. centimetre	(213 lb. per sq. in.).	
Weight, empty	64,100 kilograms	(141,318 lb.).	
— in running order	70,800 —	(156,089 lb.).	
Tractive force	10,700 —	(23,591 lb.).	
Weight, adhesive	60,800 —	(134,043 lb.).	

Fig. 54. — Boiler for 4/5 compound locomotives for goods trains. Saxon State Railway.

Explanation of the German term : Rohre = Tubes.

superheater dampers is outside the smoke-box on its left side, and consists of a small steam cylinder with piston, whose movement is transmitted to the dampers by a system of levers. The space behind the piston is in constant connection with the valve chest; consequently the piston, as long as there is pressure in the valve chest, *i. e.* as long as the regulator is open, is in its extreme position. In order that no loss of steam may occur through want of tightness in the piston, it is so designed that it in its extreme position it forms a valve, kept closed by the steam pressure. The extension of the piston at the same time forms a differential piston. The opening and the closing of the dampers can be made to take place as slowly as may be desired by the corresponding throttling of the air sucked in at every stroke and hence can be effected without any knock.

The arrangement of the dampers largely depends on the size of the locomotives. On smaller locomotives only one damper is necessary, which fits the tube-plate and allows the hot gases to pass unhindered. With boilers of larger diameter the damper, if there were only one, would have to be very large and would easily warp at higher temperatures. It must therefore be divided into several parts, usually three.

The steam collector is divided and connected with the boiler and the valve chest in such a way, that the steam is compelled to flow through all the superheater element simultaneously, in order to pass from the boiler to the cylinder. In order to improve the circulation of the water, a considerable length of the smoke tubes, at the fire-box side, is given a contracted cross-section; the part at the ends which is going to be expanded into the tube plate has grooves 0·75 millimetre ($^1/_{32}$ inch) deep turned in. Careful expansion and beading over give very satisfactory results.

The large smoke tubes and the superheater elements they contain are most easily cleaned and the soot and ashes removed by means of compressed air or steam; it is best to carry out this operation from the fire-box, but it can also be carried out from the smoke-box. Compressed air is to be preferred for this cleaning operation.

According to the statement of the inventor, Mr. Wilhelm Schmidt, engineer, the superheater tubes are made of such dimensions that the total cross-section, in square centimetres, for the steam in the superheater is about equal to 1 per cent of the piston area, in square centimetres, multiplied by the greatest mean piston speed, in metres per second.

In fixing the diameter of the smoke tubes, it is laid down as a principle that the clear cross-section available for the passage of the hot gases must not be reduced by the presence of the superheater; and it may be assumed that at the narrowest point about half the cross-section of the smoke tubes is occupied by the superheater elements. The four cross-sections of the superheater tubes occupy about 40 per cent of the clear cross-section of the smoke tubes. The proportions have given very good results.

The inventor assumes that the surface of the superheater must be equal to about 25 per cent of the total heating surface. By putting in the smoke-tube superheater the heating surface of the smoke tubes is reduced by a little less than 25 per cent:

the total heating surface is accordingly practically not altered by the presence of the superheater, but it is materially improved by the wide smoke tubes at the top and by the superheater surface.

It also has to be taken into consideration, that the heating surface of the fire-box, which is much the most effective, remains unchanged (1) (2).

c) *Description of the Pielock Superheater.*

The chief feature of this superheater is a steam chamber of approximately cubical shape, which encloses all the smoke tubes in the barrel over a certain part of their length, the smoke tubes having to be well expanded into the front and the back wall of the chamber. The diameter of the holes in the four tube-plates, from the copper tube-plate of the fire-box to the smoke-box tube-plate, increase to correspond, so that damaged tubes can be taken out through the smoke-box tube-plate. The chamber has partitions inside, which are placed longitudinally so as not to interfere with the tubes; the wet steam, which enters at the top of the superheater, is thus compelled to flow over the smoke tubes by as long a path as possible.

In order to prevent as far as possible any dangerous weakening of the smoke tubes by riveting and corrosion, they were given a brass coating inside the superheater, but without particular success. Of late the superheater chamber is filled with water when the locomotive stands still, which is emptied out when it is again going to be used.

As regards the most recent form of the Pielock superheater (see figs. 64), the following has to be noted (according to the statement of the constructors) :

As compared with the former arrangement, the speed of the steam in the superheater has been increased. This result is obtained by reducing the average size of the cross-sections of the several chambers. Each vertical row of tubes is enclosed in one chamber. In addition, above and below the smoke tubes, small pieces of sheet metal are arranged which set up eddies in the steam and guide it to the tubes. The steam no longer passes vertically, but parallel to the tubes. The superheater could accordingly be filled to one third its height with water, before water could be carried over into the cylinders. The partitions no longer simply butt against the tube-plates, but take into grooves. These grooves are either planed in, or are formed by strips riveted on. This helps to keep the separate chambers tight as against each other.

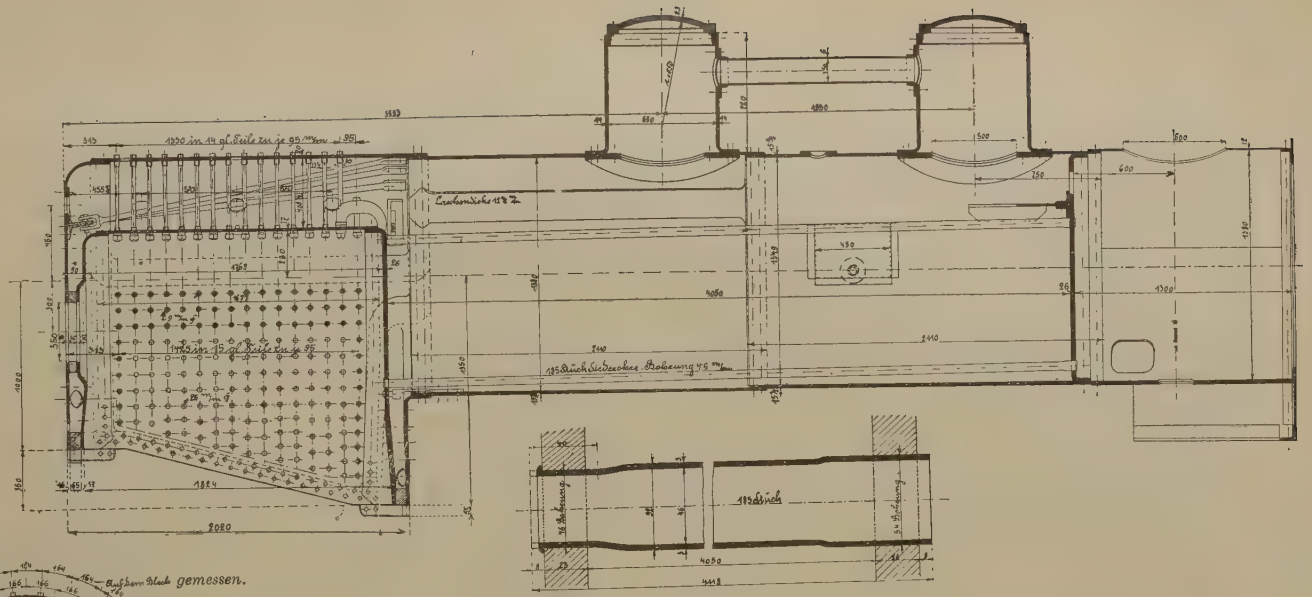
On account of the expansion by heat, the partitions are only fixed at one side, but at the bottom to one common floor plate. On the other side, they are only pushed in between clip-plates, so that they can freely expand there.

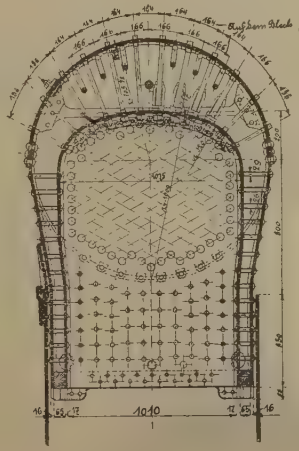
The spaces for superheated steam and for wet steam are carefully separated from each other. At all the riveted joints more rivets, and stronger rivets, are used than is necessary for keeping them together.

The connection between the superheater and the regulator is made elastic, with a view to the to and fro movements of the nest of tubes. It is so arranged that there

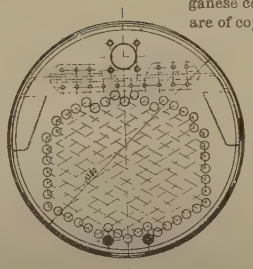
(1) See Robert Garbe, *Die Dampflokomotiven der Gegenwart*, pp. 279 and seq.

(2) We give subsequently figures 55 to 61 of wet-steam boilers so that they may be more easily compared with superheated steam boilers.





Cylinders, diameter			435 millimetres	(1 ft. 5 1/8 in.).
Length of stroke			630 —	(2 ft. 18/16 in.).
Driving wheels, diameter			1,480 —	(4 ft. 10 5/16 in.).
Working pressure			13 atmospheres.	
Test pressure			18 —	
In contact with hot gases	Heating surface, tubes		103·26 sq. metres	(1,165·53 sq. ft.).
	— —	fire-box	8·25 —	(88·80 —).
	— —	total	116·51 —	(1,254·14 —).
In contact with water	— —	tubes	122·35 —	(1,317·01 —).
	— —	fire-box	8·60 —	(92·57 —).
	— —	total	130·95 —	(1,409·58 —).
Grate area			1·83 —	(19·69 —).
Water space, under average conditions (water-level 160 millimetres (6 5/16 in.) above fire-box roof)			4·7 cubic metres	(165·98 cubic ft.).
Steam space, ditto			1·65 —	(58·27 —).
Boiler, total capacity			6·35 —	(224·25 —).
Weight, empty			48·25 tons	(47·48 English tons).
— in running order			62·50 —	(61·51 — —).
— adhesive			40·55 —	(39·90 — —).



The flexible stays are of manganese copper; the other stays are of copper.

The two top rows of the side wall and the back wall have a diameter of 29 millimetres (1 9/64 in.); all the others have a diameter of 26 millimetres (1 1/32 in.).

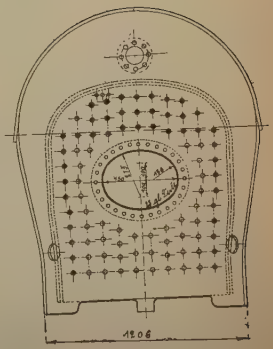
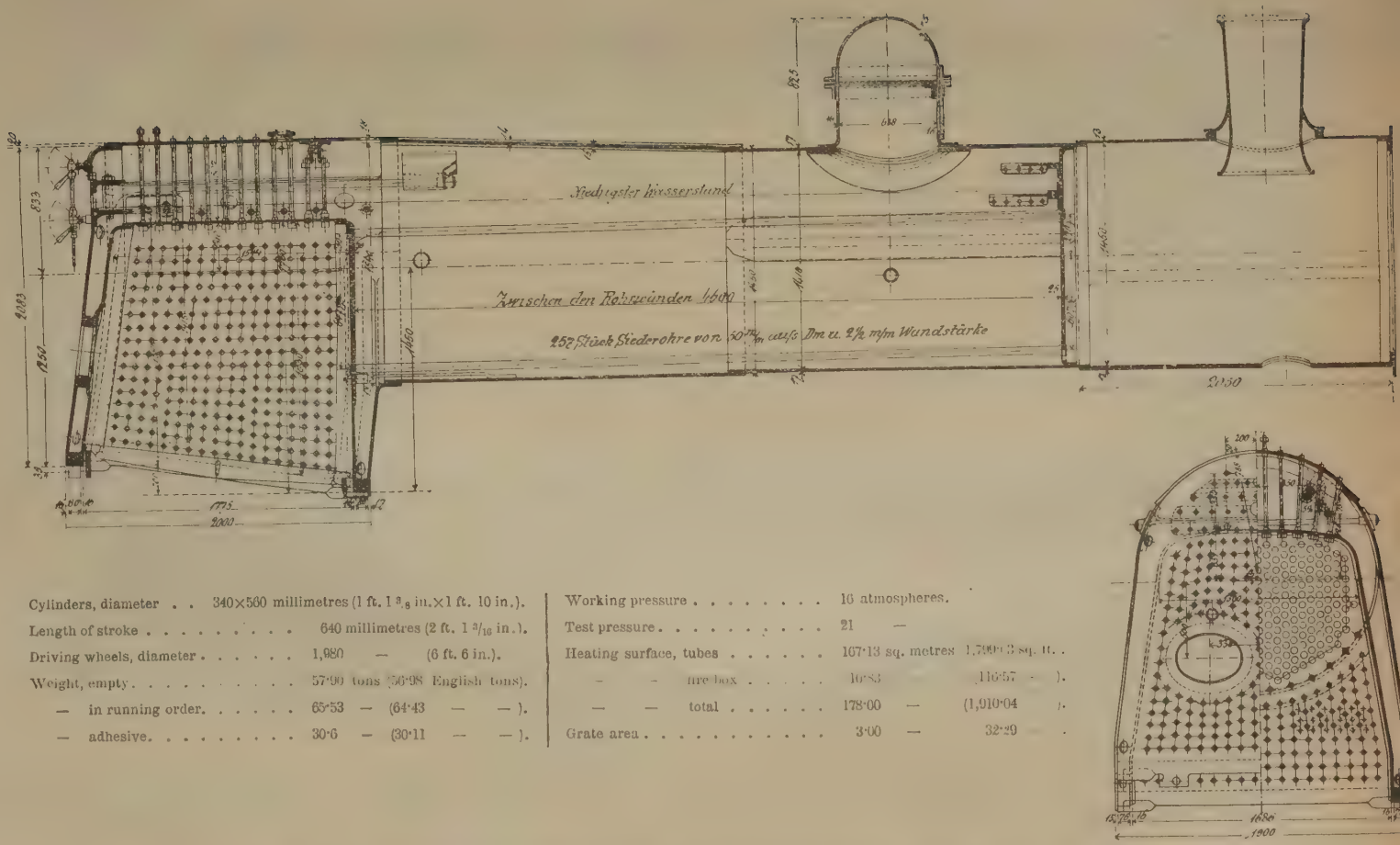


Fig. 55. — Boiler for 3/5 twin tank locomotives. Baden State Railway.

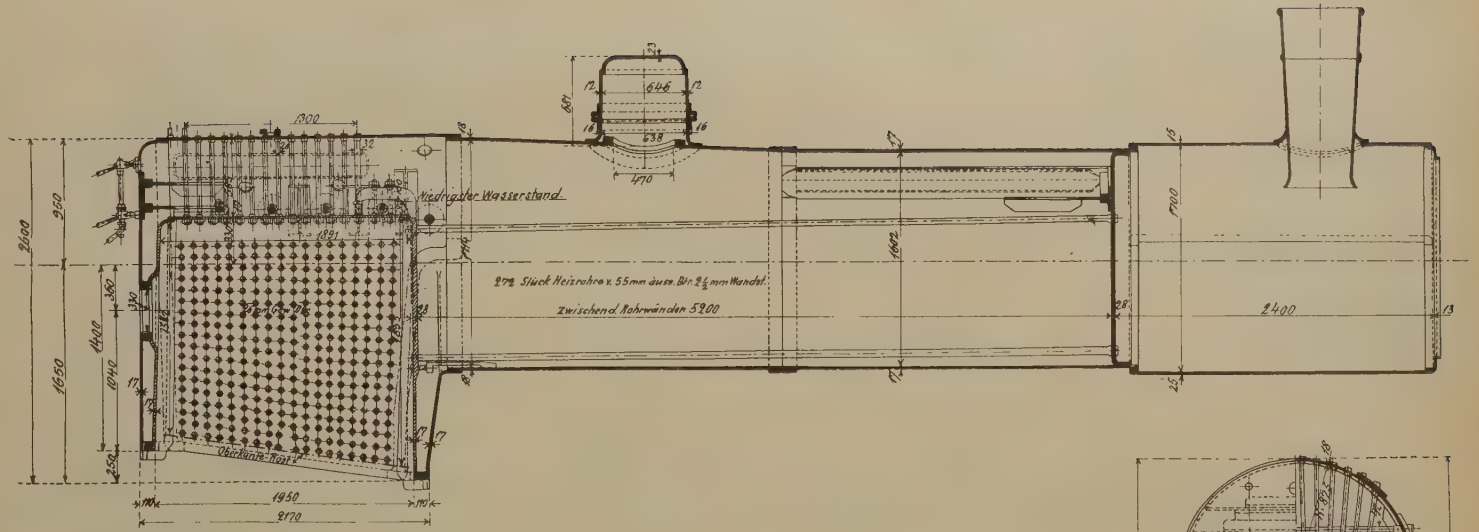
Explanation of German terms: 1,330 in 14 gl. Teile zu je 95 m/m = 1,330 in 14 equal parts of 95 millimetres (3 3/4 inches) each. — 1,425 in 15 gl. Teile zu je 95 m/m = 1,425 in 15 equal parts of 95 millimetres (3 3/4 inches) each. — Lauchenrohre 43/2 = 135 smoke-tubes, internal diameter 46 millimetres (1 13/16 inches). — 135 Rauch Siederohre Bohrung 45 m/m = 135 smoke-tubes, internal diameter 45 millimetres (1 25/32 inches). — 112 Rauch = 112 smoke-tubes. — Aufbauen Blech gemessen = measured on the plate.

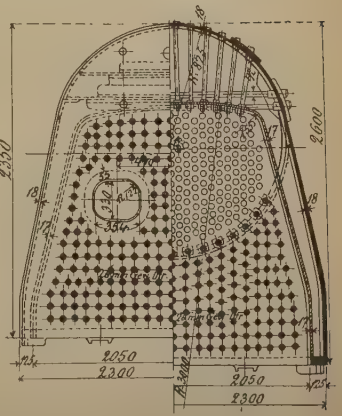


Cylinders, diameter . .	340×560 millimetres (1 ft. 1 3/8 in.×1 ft. 10 in.).			Working pressure	16 atmospheres.		
Length of stroke	640 millimetres (2 ft. 1 3/16 in.).			Test pressure	21 —		
Driving wheels, diameter	1,980 — (6 ft. 6 in.).			Heating surface, tubes	167·13 sq. metres	1,799·3 sq. ft. .	
Weight, empty	57·90 tons	(56·98 English tons).		— — fire box	10·87	(116·57 —).	
— in running order.	65·53 —	(64·43 — —).		— — total	178·00 —	(1,910·04 —).	
— adhesive.	30·6 —	(30·11 — —).		Grate area	3·00 —	32·29 — .	

Fig. 56. — Boiler for ²/₄ four-cylinder compound locomotive for express trains. Prussian-Hessian State Railway.

Explanation of German terms: Niedrigster Wasserstand = Lowest water level. — Zwischen den Rohrwänden = Between tube plates. — 257 Stück Siederohre von 50 m m äuss. Dm. u. 2 ½ m/m Wandstärke = 257 smoke-tubes, external diameter 50 millimetres (1 31/32 inches), 2·5 millimetres (3/32 inch) thick.

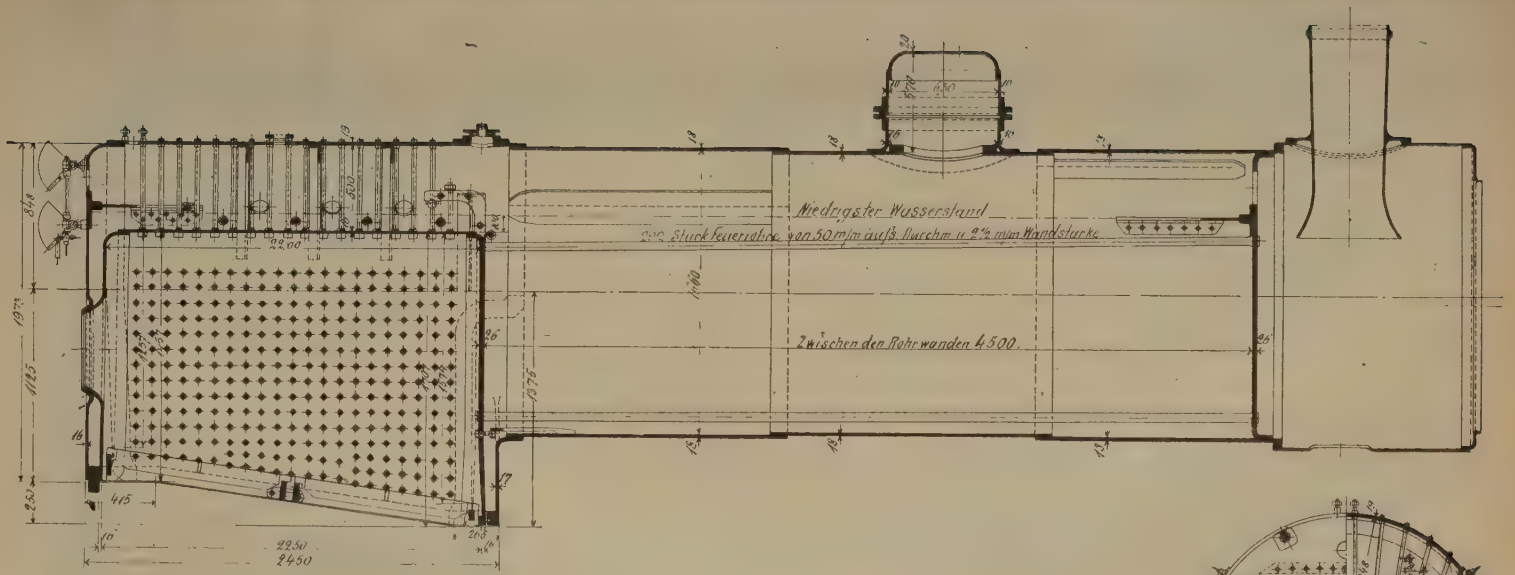


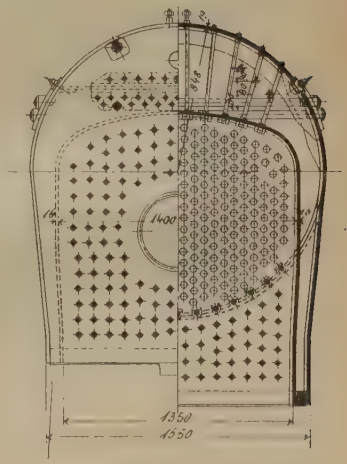


Cylinders, diameter .	380×580 millimetres (1 ft. 3 in.×1 ft. 10 13/16 in.).	Working pressure	14 atmospheres.
Length of stroke.	600 millimetres (1 ft. 11 5/8 in.).	Test pressure	19 —
Driving wheels, diameter	1,980 — (6 ft. 6 in.).	Heating surface, tubes	222·17 sq. metres (2,391·50 sq. ft.).
Weight, empty	68·8 tons (67·71 English tons).	— — fire-box . . .	14·04 — (151·13 —).
— in running order. . . .	76·9 — (75·68 — —).	— — total	236·21 — (2,542·63 —).
— adhesive	30·0 — (29·52 — —	Grate area	4·00 — (43·05 —).

Fig. 57. — Boiler for 2/5 compound locomotive for express trains. Prussian-Hessian State Railway.

Explanation of German terms : Niedrigster Wasserstand = Lowest water-level. — 272 Stück Heizrohre von 55 m/m äuss. Durchmesser u. 2 1/2 m/m Wandstärke = 272 smoke tubes, external diameter 55 millimetres (2 5/32 inches), 2·5 millimetres (3/32 inch) thick. — Zwischen den Rohrwänden 5,200 Millimeter = Between tube-plates, 5,200 millimetres (17 ft. 3/4 in.).



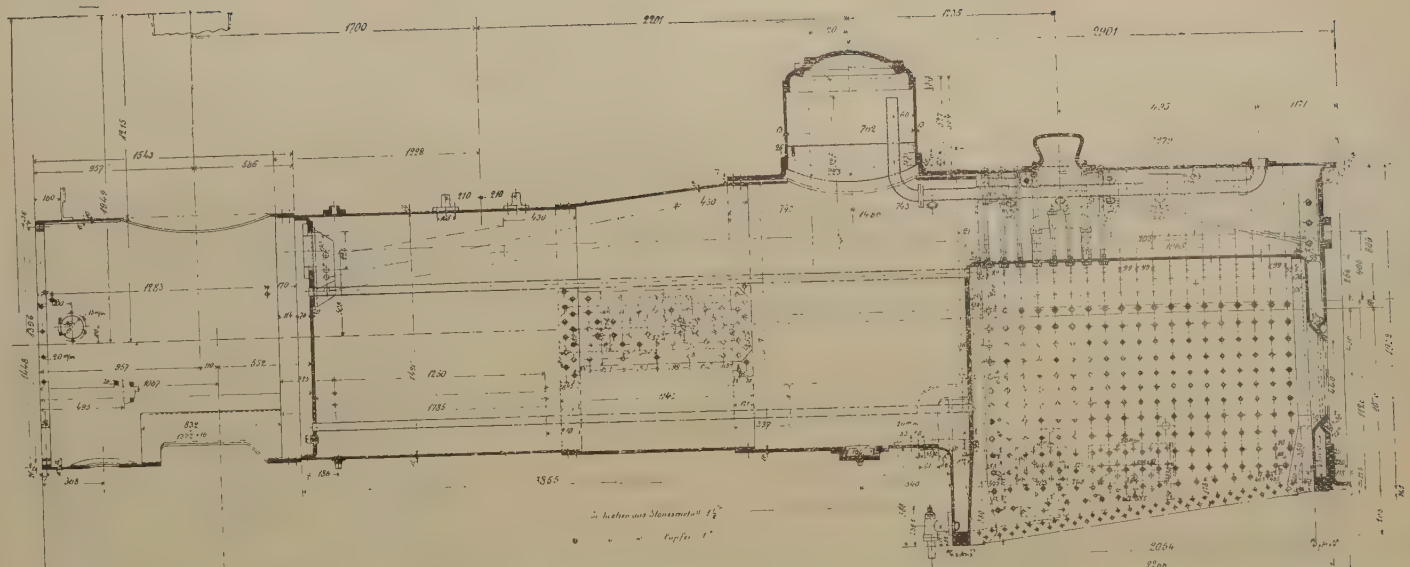


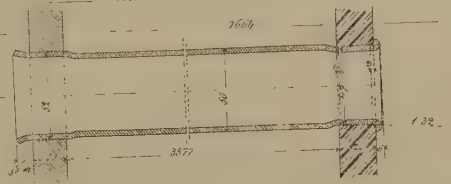
Cylinders, diameter	550 millimetres	(1 ft. 9 11/16 in.).	
Length of stroke	630 —	(2 ft. 15/16 in.).	
Driving wheels, diameter	1,250 —	(4 ft. 1 3/16 in.).	
Weight, empty	51·51 tons	(50·69 English tons.).	
— in running order	59·01 —	(58·07 — —).	
— adhesive	59·01 —	(58·07 — —).	

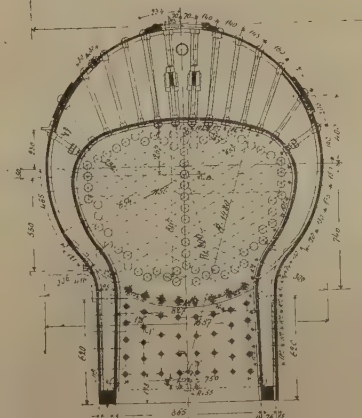
Working pressure	12 atmospheres.	
Test pressure	17 —	
Heating surface, tubes	185·76 sq. metres	(1,999·57 sq. ft.).
— fire-box	11·82 —	(127·23 —).
— total	197·58 —	(2,126·80 —).
Grate area	3·05 —	(32·83 —).

Fig. 58. — Boiler for 4/4 goods locomotive. Prussian-Hessian State Railway.

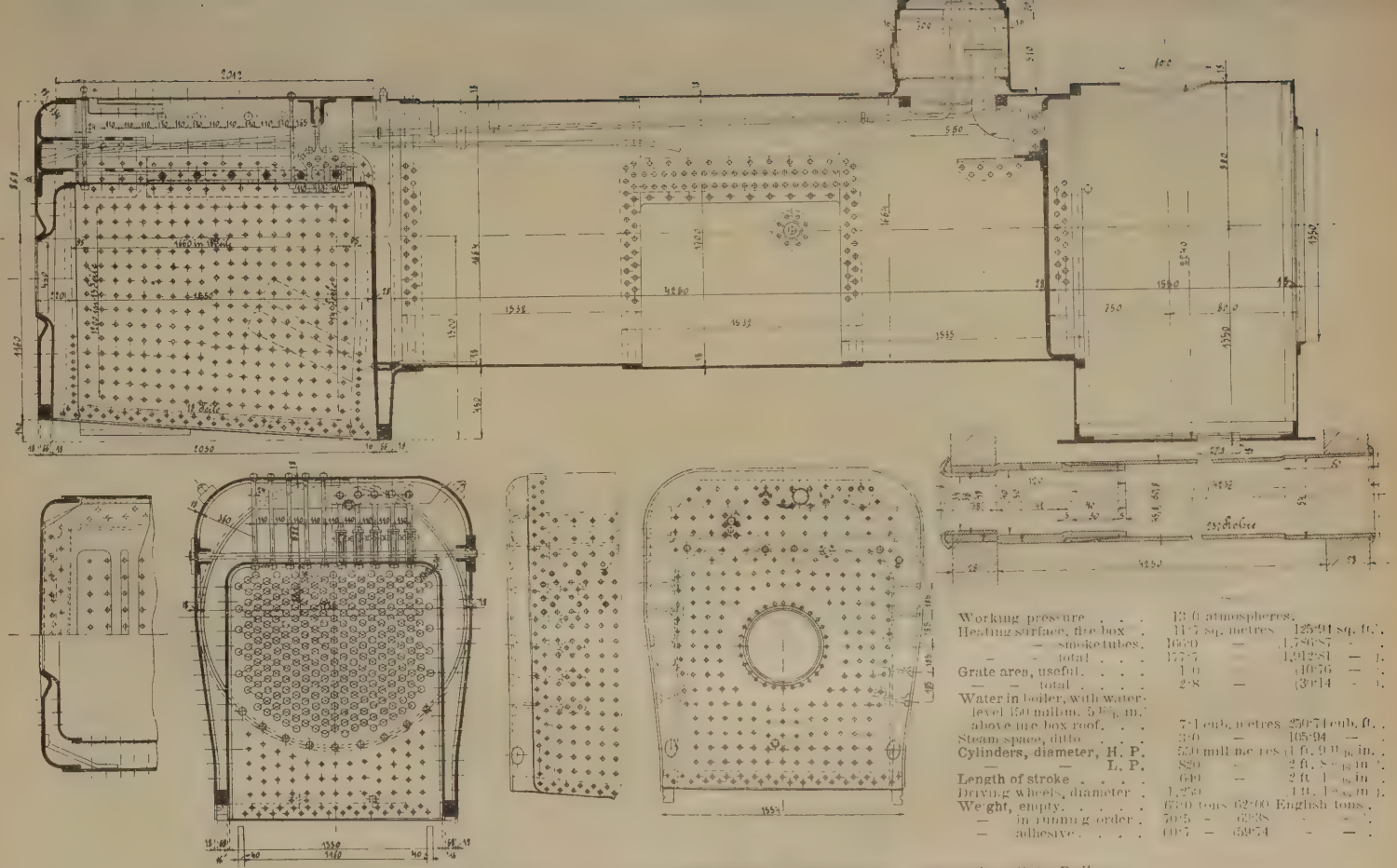
Explanation of German terms: Niedrigster Wasserstand = Lowest water level. — 292 Stück Feuerrohre von 50 m/m ausserer Durchmesser und 2 1/2 m/m Wandstärke = 292 smoke tubes, external diameter 50 millimetres (1 31/32 inches), 2·5 millimetres (3/32 inch) thick. — Zwischen den Rohrwänden 4,500 Millimeter = Between tube-plates, 4,500 millimetres (14 ft. 9 3/16 inches).







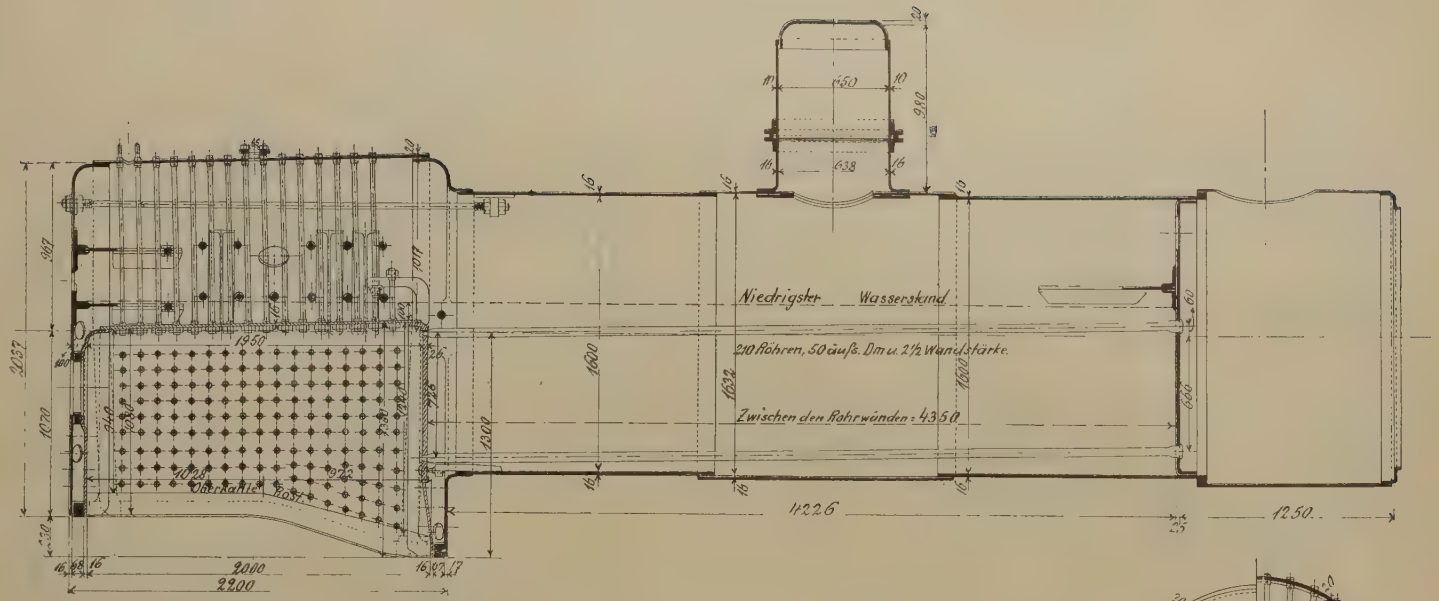
Grate area	1·7 sq metres (18·29 sq. ft.).
Heating surface, fire-box	16·47 — (177·28 —).
— — smoke tubes	125·18 — (1,347·47 —).
— — total	135·65 — (1,460·17 —).
Working pressure	13·5 atmospheres.
Boiler, water space	5·45 cubic metres 192·47 cubic ft.).
Cylinders, diameter, H. P.	508 millimetres (1 ft. 8 in.).
— — L. P.	787 — (2 ft. 7 in.).
Length of stroke	610 — (2 ft.).
Driving wheels, diameter	1,572 — (5 ft. 1 $^{15}/_{16}$ in.).
Weight, empty	51·25 tons (50·44 English tons).
— in running order	56·70 — (55·80 —).

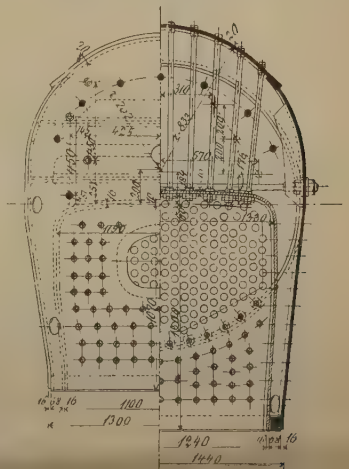


Working pressure . . .	13·0 atmospheres.	
Heating surface, fire-box .	11·7 sq. metres	125·91 sq. ft.
— smoke-tubes.	166·0 —	1,786·87 —
— total . . .	177·7 —	1,912·81 —
Grate area, useful. . . .	1·0 —	10·76 —
— — total . . .	2·8 —	30·14 —
Water in boiler, with water-level 150 millim. 5$\frac{29}{32}$ in. above fire-box roof. . .	7·1 cub. metres	250·74 cub. ft.
Steam-space, ditto . . .	3·0 —	105·94 —
Cylinders, diameter, H. P.	550 mill. metres	1 ft. 9 $\frac{11}{16}$ in.
— — L. P.	820 —	2 ft. 8 $\frac{5}{16}$ in.
Length of stroke	640 —	2 ft. 1 $\frac{3}{16}$ in.
Driving wheels, diameter .	1,250 —	4 ft. 1 $\frac{3}{16}$ in.
Weight, empty.	63·50 tons	62·00 English tons.
— in running order .	70·35 —	69·28 — —
— adhesive. . . .	60·07 —	59·74 — —

Fig. 60. — Boiler for $1'_5$ two-cylinder compound locomotive for goods trains. Norwegian State Railway.

Explanation of German terms: ... Teile = s, — ..., in"... Teile = ..., divided into ... parts.





Working pressure	12 atmospheres.
Test pressure	17 —
Heating surface, tubes	129·14 sq. metres (1,390·10 sq. ft.).
— — fire-box	8·39 — 90·31 — .
— — total	137·53 — 1,480·41 —).
Grate area	2·37 — 25·51 — .
Cylinders, diameter	520 millimetres (1 ft. 8 15/32 in.).
Length of stroke	630 — (2 ft. 25/32 in.).
Driving wheels, diameter	1,200 — (3 ft. 11 1/4 in.).
Weight, empty	57·0 tons (56·03 English tons).
— in running order	72·28 — (71·13 — —).

Fig. 61. — Boiler for 5/5 tank locomotive for goods trains. Prussian-Hessian State Railway.

Explanation of German terms: Oberkante = Upper edge. — Rost = Grate. — Niedrigster Wasserstand = Lowest water-level. — 210 Röhren, 50 äuss. Durchm. und 2½ Wandstärke = 210 tubes, external diameter 50 millimetres (1 31/32 inches) 2·5 millimetres (3/32 inch) thick. - Zwischen den Rohrwänden 4,350 Millimeter = Between tube-plates, 4,350 millimetres (14 ft. 3 9/32 inches).

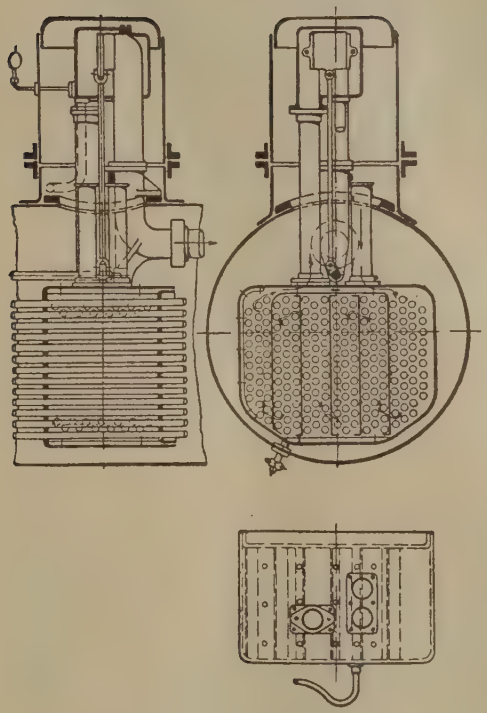


Fig. 62. — Pielock superheater.

is no communication whatever with the surrounding wet steam.

In order to prevent the rusting of the smoke tubes, which has occasionally taken place in the Pielock superheater, the chamber is filled with water, either automatically or by hand, when the locomotive has finished its work. Before starting work again, this water is then drawn off, as soon as the steam in the boiler attains a pressure of about half an atmosphere. The automatic device provided for this purpose has it is true not yet given permanently-satisfactory results, as it has occasionally failed to act.

In cases when it is only desired to superheat the steam slightly, the Pielock steam drier has been put in next the smoke-box tube-plate. It is constructed like the superheater. One of the chamber tube-plates however becomes unnecessary, as it is replaced by the smoke-box tube-plate. Accordingly there are only three points left at which the smoke tubes have to be expanded.

d) *Description of the Clench-Gölsdorf superheater.*

The superheater is in the front part of the barrel. At a distance of 1 metre

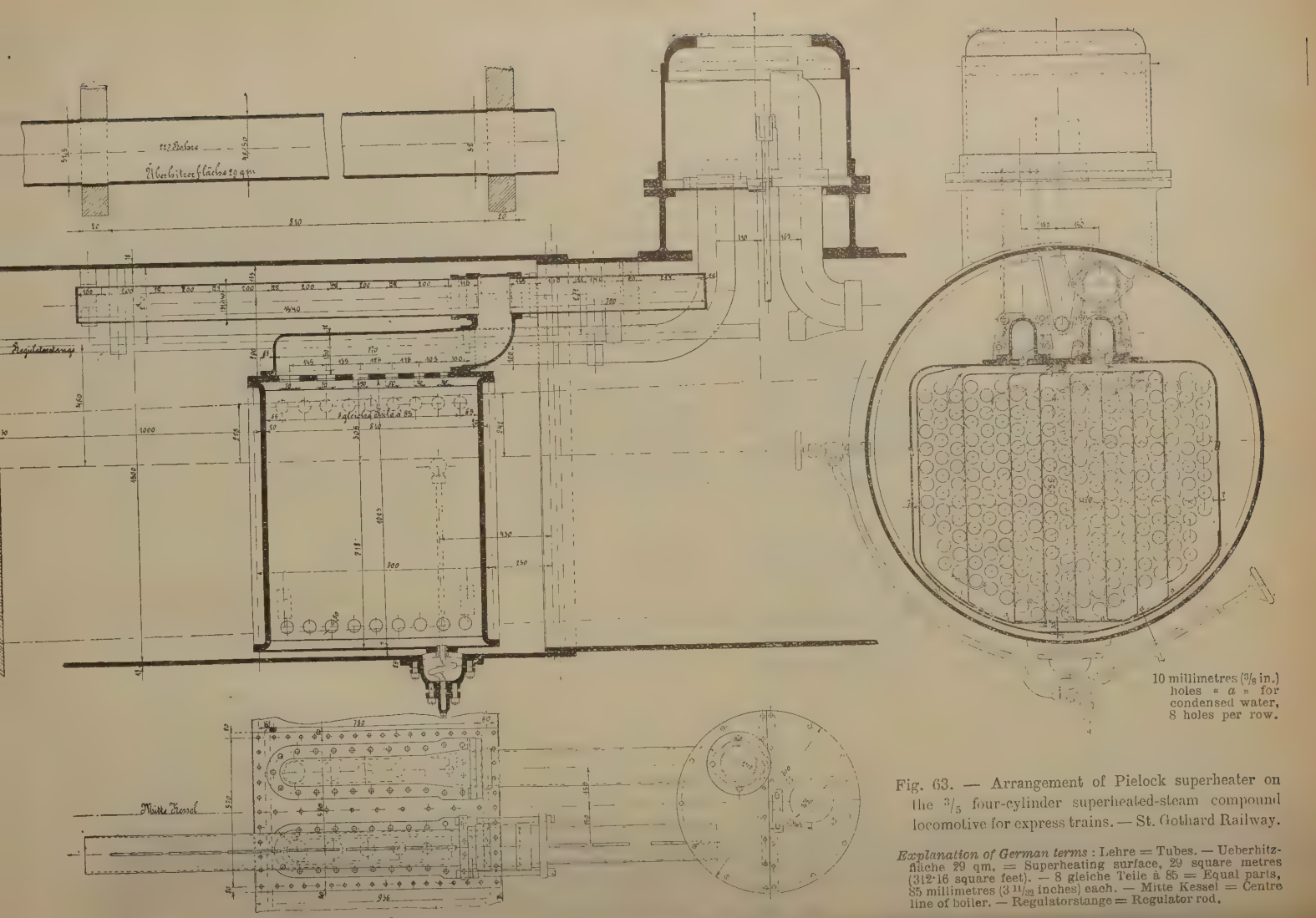
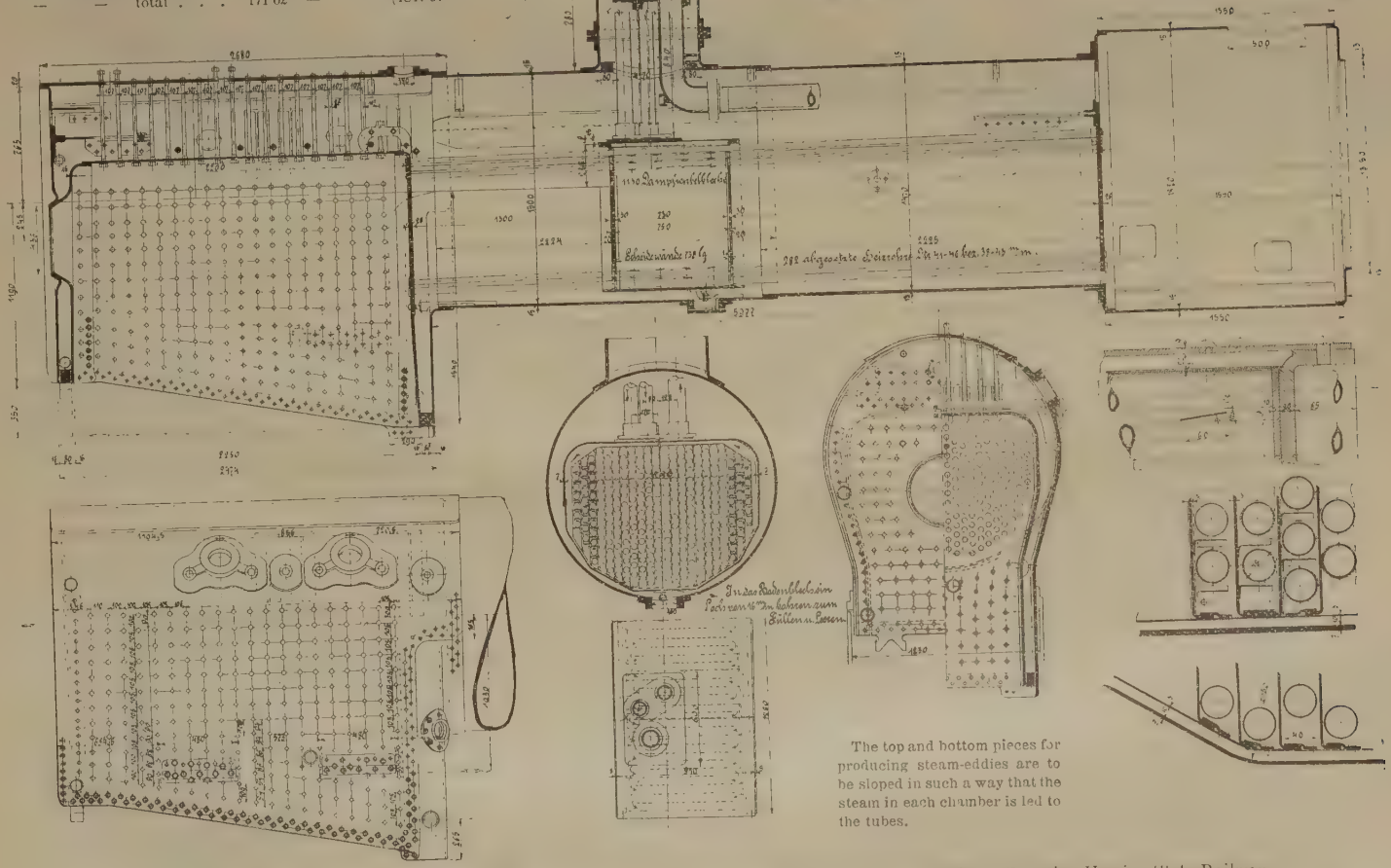


Fig. 63. — Arrangement of Pielock superheater on the $^3/_5$ four-cylinder superheated-steam compound locomotive for express trains. — St. Gothard Railway.

Explanation of German terms : Lehre = Tubes. — Ueberhitzfläche 29 qm. = Superheating surface, 29 square metres (312·16 square feet). — 8 gleiche Teile à 85 = Equal parts, 85 millimetres (3 11/32 inches) each. — Mitte Kessel = Centre line of boiler. — Regulatorstange = Regulator rod.

Heating surface, fire-box		11·44	—	—	(123·15
—	—	smoke tubes.	160·08	—	—	(1723·15	—	—
—	—	total . . .	171·62	—	—	(1847·37	—	—

—	adhesive.	46·4900	—	(101,414 lb.).



The top and bottom pieces for producing steam-eddies are to be sloped in such a way that the steam in each chamber is led to the tubes.

Fig. 64. — Boiler with Pielock superheater for $^3/_4$ twin superheated-steam locomotive for passenger trains. Prussian-Hessian State Railway.

Explanation of German terms: Scheidewände = Partitions. — Dampfwirbelbleche = Sheet iron for producing eddies of steam. — 282 abgesetzte Heizrohre Nr. 41-46 bez. 38-43 m/m = 282 smoke tubes, diameters 41 × 46 millimetres ($1\,^5/_8 \times 1\,^{13}/_{16}$ inches) and 38 × 43 millimetres ($1\,^{17}/_{32} \times 1\,^{23}/_{32}$ inches). — In das Bodenblech ein Loch von 16 m/m bohren zum Füllen u. Leeren = There is a 16 millimetre ($^5/_8$ inches) hole in the bottom plate for filling and emptying.

(3 ft. 3 $^3/_8$ in.) from the smoke-box tube-plate a steam-tight cross partition is put up, which closes off the front part from the boiler water. The superheating space so obtained contains three partitions, which however do not extend to the top of the barrel, but are closed by a horizontal roof. The smoke tubes passing through the three partitions do not have steam-tight joints in these partitions, as they have in the first cross partition, but pass through holes with more or less play. The gaps between partitions and tubes are so arranged that in the front chamber, which the steam coming from the dome enters, small gaps (0·5 millimetre [$^3/_{128}$ in.]) are in the upper two thirds of the partition and large gaps (1 millimetre [$^3/_{64}$ inch]) in the lower third. In the second partition the upper gaps are larger (2 millimetres [$^5/_{64}$ inch]) and the lower gaps smaller (1 millimetre [$^3/_{64}$ inch]); in the third partition the position is again reversed, the upper gaps being smaller and the lower gaps larger. Thus the small gaps are always immediately opposite the entering steam, so that it is compelled also to flow through the larger gaps which are further away. This is intended to make the steam flow transversely to the smoke tubes as well as along them, so as to take up as much heat as possible. After the steam has passed through the third partition it flows over the flat roof of the chambers to the regulator which is above.

This variation in the sizes of the gaps was first introduced on the locomotives of the Baden State Railway (fig. 65).

Most of the administrations use the Schmidt smoke-tube superheater, while the smoke-box superheater is now no longer made. The Pielock superheater is used on twelve locomotives of the Prussian-Hessian State Railway, on one locomotive of the Stockholm-Rimbö Railway and on six locomotives of the St. Gothard Railway. The Clench-Gölsdorf superheater is used on ten locomotives of the Baden State Railway, on sixteen locomotives of the St. Gothard Railway, and also on the Swedish State Railway.

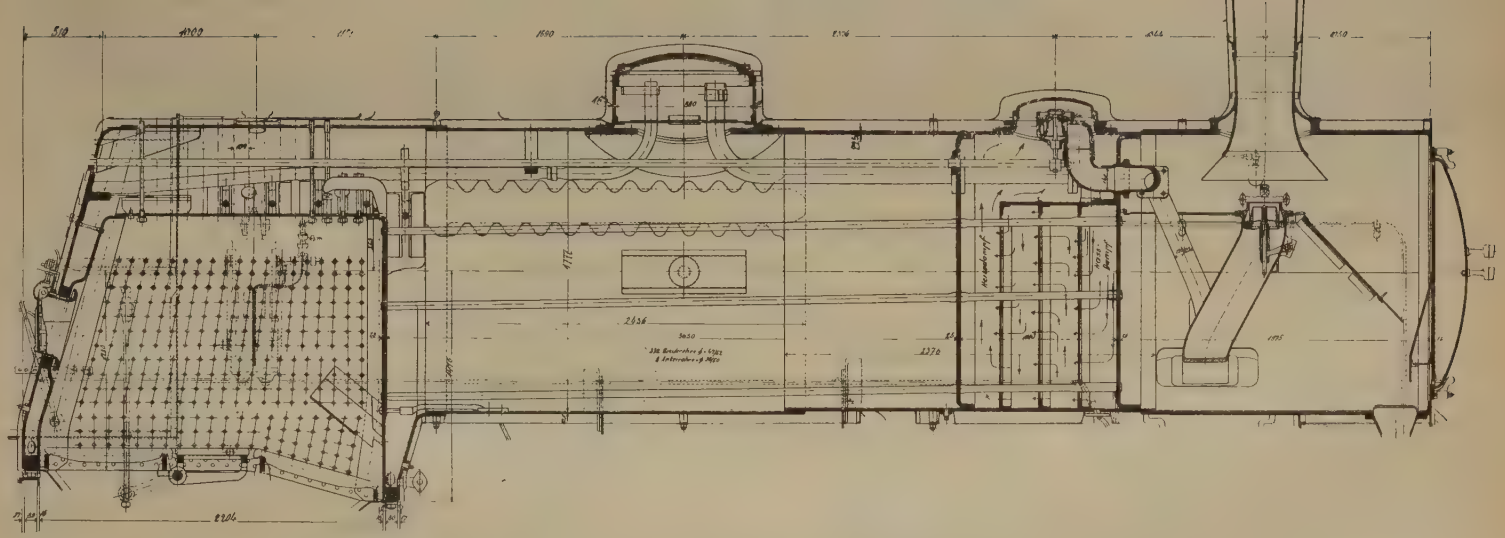
The superheater steam is in most cases used on twin locomotives, but of late it also is frequently used on four-cylinder compound locomotives.

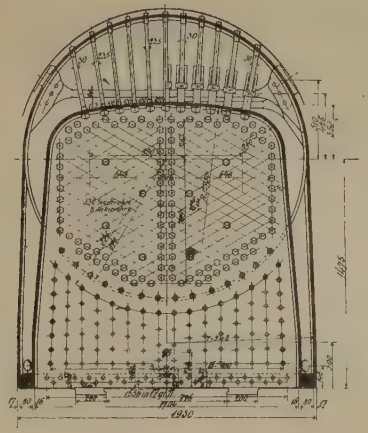
2. *Valve gear for superheated steam.* — Piston valves alone are used for superheated steam; they are generally of the Schmidt design and used in combination with the Heusinger link motion. Trials are being made on the St. Gothard Railway with a locomotive fitted with Lentz poppet-valve gear; on another locomotive the high-pressure cylinder has a piston valve and the low-pressure cylinder a relieved flat slide valve. The Prussian-Hessian State Railway is also making trials with poppet-valve gear and supplies the following information :

The valve gear of the superheated-steam locomotives of the administration of the Prussian State Railway includes, with few exceptions, piston valves with solid rings; flat slide valves are not used on superheated-steam locomotives.

A number of locomotives have been fitted with Lentz poppet-valve gear as an experiment, and several superheated-steam locomotives are fitted with piston valves with elastic rings.

In making the piston valves with solid





Cylinder, diameter	H. P. 2 × 395 (1 ft. 3 $^{9}/_{16}$ in.);	L. P. 2 × 635 millimetres (2 ft. 1 in.).	
Length of stroke		640 millimetres (2 ft. 1 $^{3}/_{16}$ in.).	
Driving wheels, diameter		1,350 — (4 ft. 5 $^{3}/_{16}$ in.).	
Working pressure		16 atmospheres.	
Heating surface, fire-box, internal		13	sq. metres (139·93 sq. ft.).
— — smoke tubes, internal		182	— (1,959·10 —).
— — total, saturated steam		195	— (2,099·03 —).
Superheating surface (Clench-Gölsdorf superheater)		50	— (538·21 —).
Heating surface, grand total		245	— (2,637·24 —).
Grate area		3·75	— (40·36 —).
Steam space (water-level 100 millimetres (3 $^{15}/_{16}$ inches) above fire-box roof)		4·45 cubic metres (157·16 cubic ft.).	
Water space, ditto		5·8	— — (204·83 —).
Total capacity of boiler		10·25	— — (361·99 —).
Weight, empty		71·35 tons (70·22 English tons).	
— in running order		78·06	— (76·82 — —).
— adhesive		66·63	— (65·57 — —).

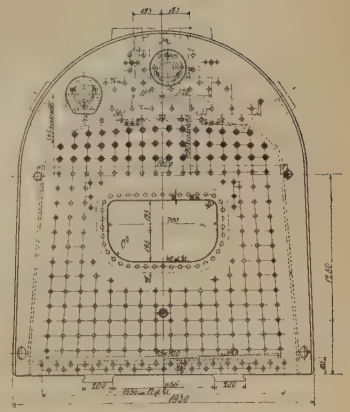
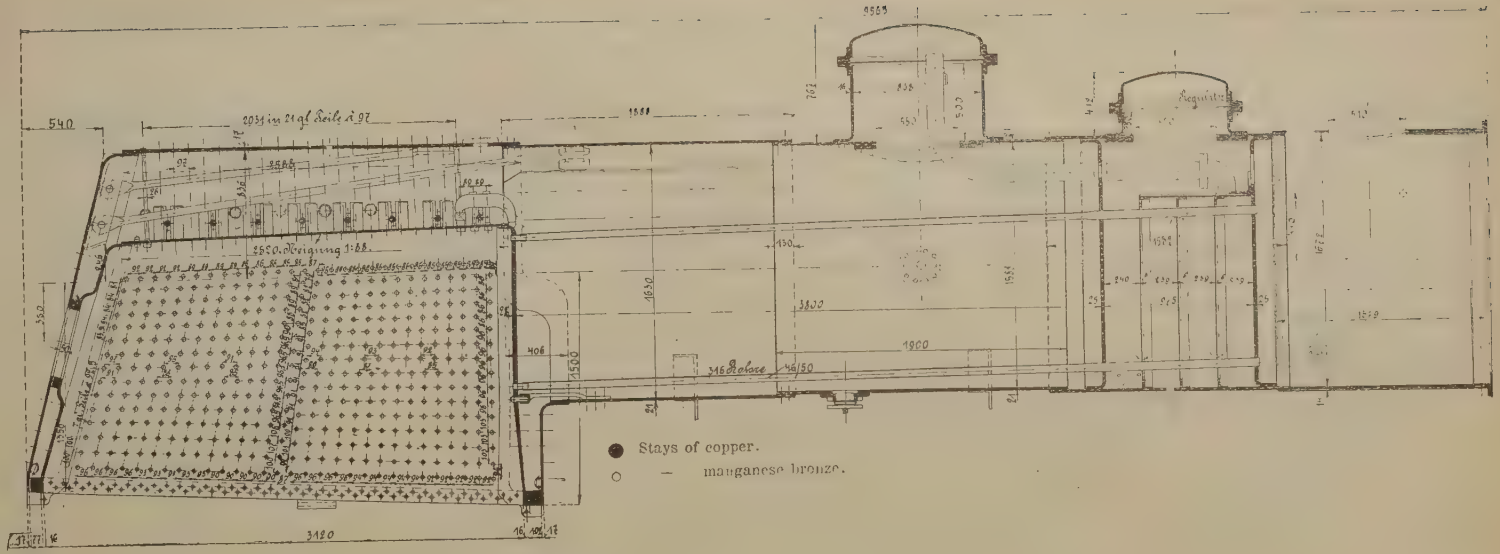
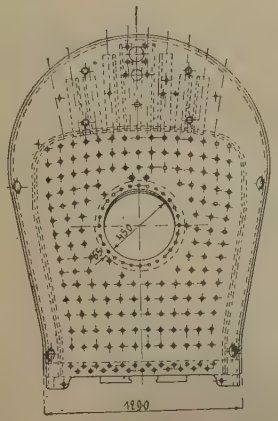
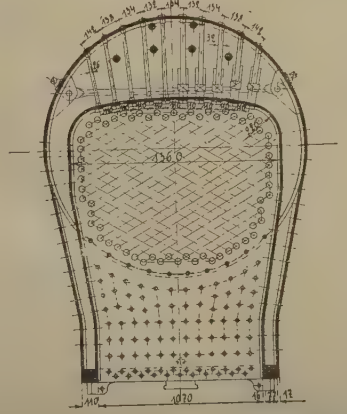


Fig. 65. — Boiler for $^{4}/_{5}$ four-cylinder compound locomotives for goods trains. Baden State Railway.

Explanation of German terms: Nassdampf = Wet steam. — Heissdampf = Superheated steam. — ... Siederohre, ⌀ ... = ... smoke tubes, diameter ... — ... Ankerrohre, ⌀ ... = ... stay tubes, diameter ...







Working pressure	15 atmospheres.	
Test pressure	20 —	
Heating surface, fire-box	15·4 sq. metres	(165·77 sq. ft.).
— — tubes	172·2 —	(1,853·61 —).
— — total, saturated steam	188·6 —	(2,030·15 —).
— — superheater	47·4 —	510·22 —).
— — grand total	236·0 —	(2,540·37 —).
Grate area	3·34 —	35·65 —).
Water space (water-level 150 millimetres (5 $^{29}/_{32}$ inches) above fire-box)	6·20 cub. metres	(222·49 cub. ft.).
Steam space in boiler	2·40 —	(84·75 —).
— — superheater	1·50 —	(52·97 —).
Cylinders, diameter	395 & 635 millimetres.	(1 ft. 3 $^{9}/_{16}$ in. & 2 ft. 1 in.)
Length of stroke	646 millimetres	(2 ft. 1 $^{9}/_{16}$ in.).
Driving wheels, diameter	1,610 —	(5 ft. 3 $^{7}/_{8}$ in.).
Weight, empty	73·3 tons	(72·14 English tons).

Fig. 66. — Boiler for $^{3}/_{5}$ four-cylinder superheated-steam compound locomotives for express trains. St. Gothard Railway. Clench-Gölsdorf superheater.

Explanation of German terms: 316 Rohre = 316 tubes. - 2,037 in 21 gl. Teile à 97 = 2,037 in 21 equal parts of 97 millimetres (3 $^{13}/_{16}$ inches) each. Neigung = Inclination
7 gl. Teile à 92·5 = 7 equal parts of 92.5 millimetres (3 $^{21}/_{32}$ inches) each.

rings, several points have to be observed, which the experience of several years of working has shown to be necessary. Particulars are given by R. Garbe, in *Die Dampflokomotiven der Gegenwart*, p. 322.

The Heusinger link motion is that used on the superheated-steam locomotives. The comparatively-long connecting rods of all classes of superheated-steam locomotives make it possible to have long

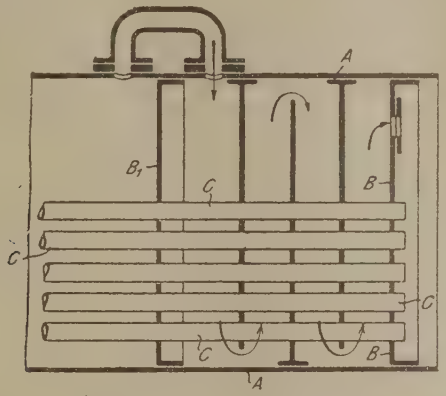


Fig. 67. — The Clench superheater.

eccentric rods and valve rods, and so obtain a good arrangement of this link motion, which acts well even on tank locomotives, both when running forwards and when running backwards.

As the piston valves are very tight and run with hardly any friction, it has been possible to have a long stroke, as well as a great reduction in the weight and a reduction in the size of all the details of the valve gear (1).

3. *Steam Piston. Piston-valve rings. Equalizing pipes. Cylinder safety valves and air-admission valves.* — The Prussian-Hessian State Railway makes the following remarks on the subject :

In order to obtain tightness combined with freedom of movement of the steam pistons, care has to be taken that the three light rings in no way help to support the piston, but are only pressed against the walls of the cylinder by their own small weight and by the very slight pressure of the steam acting behind them. Three rings are used, in order that the middle one may always remain in contact with the cylinder walls. A small groove is turned into each ring; six holes 3 millimetres ($^1/_8$ inch) in diameter lead from this groove to the groove which forms the ring seat in the piston head. When the first or the third ring is compressed, at the dead points, by the steam, this at once enters through the small passage exposed at the ends of the piston ring into the groove and stops the compression. At the same time, part of this steam again escapes by the small holes in the ring, so that the

(1) See Robert Garbe, *Die Dampflokomotiven der Gegenwart*, pp. 329 and 437.

ring is only brought back very gently into contact with the cylinder. The body of the piston is made as light as possible. The outer corners of the ring seats are rounded considerably, the inner ones a little less, in order that the piston body may bear on the cylinder walls lightly, distribute the lubricating oil well, and slide easily. The diameter of the body of the piston is 3 millimetres ($^1/_8$ inch) less than the bore of the cylinder, in order that the pressure between the body of the piston and the walls of the cylinder may be as low as possible, so as to reduce wear. From time to time, the rings must be examined in order to see that they are free to move laterally, the front stuffing boxes of the piston rod renewed, the slide bars adjusted and any sharp corners produced on the piston rings again rounded. The piston must be carried in front by a tail-rod guide, in front of the stuffing box, and at the back by the cross-head, so that the stuffing boxes only ensure tightness while not helping to carry the weight of the piston. If the piston is kept as nearly centered as possible, by the proper adjustment of the cross-head slippers and the renewal of the tail-rod guide, as is absolutely necessary for regular working, then proper tightness is obtained and the packing rings of the stuffing boxes will last for years; the different parts wear remarkably little.

As already stated in the answer to question B-b-2, the superheated-steam locomotives of the administration of the Prussian State Railway are nearly all fitted with piston valves with solid rings. In order to keep them tight, the body of the piston and the rod do not bear on the rings, so that the light rings are unloaded when moving to and fro, and are kept covered by a film of oil on which they slide and hence become worn very little. The weight of the rod together with its built-up piston is supported by long labyrinth boxes at both ends of the rod, and care is taken that the rings are free laterally. In order to keep out ashes, hot gases and other foreign bodies, which might be drawn in from the smoke-box through the blast pipe, when running with regulator closed, a pressure-equalizing device is provided and operated, and air-admission valves are fitted to the top and the bottom of the steam cylinder. Up till now, the piston valves of superheated-steam locomotives are nearly all fitted with solid rings. Such a piston valve has the following advantages, besides those already mentioned in the answer to question B-*b*-2, as compared with pistons with spring rings :

Pistons of one and the same size are made for all classes of superheated-steam locomotives in a very simple manner out of cast bodies, which are turned and ground to a standard size, so as to be interchangeable. The same arrangement of valve chest can hence be used on all cylinders, and stuffing boxes are eliminated; the valves are easily put in or taken out, and are very light, so that the friction is reduced to a minimum. The wear is so slight, that with proper treatment (keeping the valve-rod guides in good condition, taking care that the rings have freedom of lateral movement, keeping out foreign substances from the smoke-box, which increase wear) the simple solid valve rings can be used for several years, and the wear at all the joints of the link motion is very slight. These piston valves want but little

lubrication while they are being used, and very little power is required to work them. The link motion remains in position without fixing and is very easily operated, and makes the work of the driver much lighter. Taking into consideration the design of the valve and liner, improvements in these and in the valve chest are generally speaking hardly to be expected, particularly not if the proper care is taken. If a ring becomes defective through neglect, it is easy and cheap to replace it.

Piston valves with spring rings have the advantage of greater tightness at first, but the disadvantages that more power is required to overcome the friction, that they wear more quickly and that repairs are more frequently required. In addition, the liners become worn to a barrel shape over the length corresponding to the most usual cut-off, by the pressing rings, behind which the steam pressure acts; and they are then no longer steam-tight and require renewal.

The cylinders of the superheated-steam locomotives have their two ends connected by a by-pass, 65 millimetres ($2\,^9/_{16}$ inches) in diameter, in which there is a cylindrical rotary valve which can be operated from the cab. In order to keep this from sticking in its box which becomes heated by the steam, it is only made a loose fit, as it is kept tight by the steam pressure, which holds it against its seat. A short valve spindle, the outside of which is squared, has at its other end a clutch taking into grooves in the rotary disk; behind this clutch there is a valve-like projection which takes against the insides of the valve chamber, forming a tight joint; the spindle accordingly requires no packing, and is easily turned by its square end. This arrangement makes smooth running possible with the regulator closed; the rotary valve is then opened by hand and a connection between the two sides of the piston established. This device also helps to prevent hot gases from being drawn into the cylinders from the smoke-box. Air-admission valves having a clear diameter of at least 40 millimetres ($1\,^9/_{16}$ inches) are provided for the same purpose; and these, together with the equalizing pipe, must reduce the quantity of smoke, soot and hot gases drawn in from the smoke-box.

Now that the air-admission valves are made of steel, and the smaller ones replaced by larger ones, these valves give good results. The use of the piston valves makes it necessary for the cylinders to be fitted with two safety valves, one at the top and one at the bottom; these valves are loaded to the standard pressure of the boiler. Each mud valve has also a safety valve in combination, so that each cylinder has at each end two safety valves to prevent any water-hammer effects in the cylinders when starting with them cold or if priming takes place and water is carried over. The safety valves are fitted as far as possible to the lowest points of the top and bottom of the cylinder.

The other administrations use on their superheated-steam locomotives steam pistons with three cast-iron spring rings, some with grooves and small holes, others without, made in the usual way with lapped joints, as for instance the Baden State Railway, the Swedish State Railway, the Swiss Federal Railway and the St. Gothard Railway.

The Baden State Railway, the Saxon State Railway, the Wurtemberg State Rail-

way, the Swedish State Railway, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway use piston valves exclusively; these, contrary to the practice on the Prussian-Hessian State Railway, are fitted with spring rings of the Schmidt type. These administrations find that it is very difficult to keep piston valves with solid rings tight; in course of time they allow much steam to leak past and work uneconomically, particularly in cases of heavy work (running uphill). Their experience has accordingly led them to use spring rings for piston valves, and better results are obtained with them. The Bavarian State Railway, owing to the short time they have been in use, has not decided which arrangement is to be preferred.

Equalizing tubes as used on the Prussian-Hessian State Railway are also used by the Saxon State Railway and the Wurtemberg State Railway, in some cases also by the Swiss Federal Railway (without air-admission valves) and by the Rhetian Railway. These administrations consider them very useful for preventing any knocking when running with regulator closed, and for preventing injurious matter from entering the cylinders. Such equalizing tubes are not used on the Baden State Railway, the Bavarian State Railway, the Swedish State Railway and the St. Gothard Railway.

Safety valves and air-admission valves on the cylinders are used by all the administrations, except that the Swiss Federal Railway has no air-admission valves on its $^3/_4$ passenger locomotives and its $^4/_5$ goods locomotives, nor has the Rhetian Railway such valves in its locomotives.

4. *Piston-rod and valve-rod packing.* — Metallic packing is everywhere used for piston rods and valve rods; the alloy used has the following composition :

	Lead.	Tin.	Antimony.
Prussian-Hessian State Railway Swedish State Railway	65	20	15
Bavarian State Railway Saxon State Railway St. Gothard Railway	76	14	10
Wurtemberg State Railway Swiss Federal Railway	80	...	20

The packing used for the stuffing boxes for piston rods and valve rods is nearly always that proposed by W. Schmidt or else is very similar. The valve rods generally have labyrinth packing (1).

5. *Pistons rods. Metal used for the pistons, piston rings and cylinders.* — The pistons on nearly all the railways, are pressed on to the taper end of the piston rod (taper 1 : 18 to 1 : 20) and secured by a nut and cotter. On the Prussian-Hessian State Railway the pistons are put on hot and secured by a nut. The low-pressure pistons of the superheated-steam com-

(1) See GARBE, *Die Dampflokomotiven der Gegenwart*, pp. 311 and 319 and *Bulletin of the Railway Congress*, 1908, May, p. 549.

pound locomotives of the Baden State Railway are screwed on and locked.

The piston bodies are made of steel castings on the Prussian-Hessian State Railway, the Saxon State Railway, the Wurtemberg State Railway, the Swedish State Railway, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway. The Prussian-Hessian State Railway specifies mild steel having an ultimate tensile strength of at least 50 to 60 kilograms per square millimetre (71,114 to 85,336 lb. per square inch) and an elongation of at least 20 per cent, while the Saxon State Railway only specifies an ultimate tensile strength of 38 to 45 kilograms per square millimetre (54,046 to 64,002 lb. per square inch), and also an elongation of at least 20 per cent. The Baden State Railway uses cast-iron castings for the high-pressure and ingot-iron castings for the low-pressure piston bodies; the Bavarian State Railway uses cast iron for the latter if small, and steel castings if large. The Swedish State Railway uses a medium-hard cast steel.

The Prussian-Hessian State Railway and the St. Gothard Railway specify, for the piston rings, cast iron that has an ultimate tensile strength from 12 to at most 14 kilograms per square millimetre (17,067 to 19,912 lb. per square inch), and is as dense and tough as possible. It must be possible to straighten the finished rings by hammering. The other administrations state that they use soft, very dense, tough cast iron for this purpose, but give no particulars as to strength. The Saxon State Railway uses piston rings mad of crucible cast iron; the Wurtemberg State Railway and the Baden State Railway use tough cylinder cast iron, which is slightly softer than the metal used for the cylinders.

Cylinders are made of hard cast iron, which is as uniform and as dense as possible and has an ultimate tensile strength of 18 to 24 kilograms per square millimetre (25,601 to 34,134 lb. per square inch); the Swedish State Railway uses cast iron to which steel turnings have been added.

On the Prussian-Hessian State Railway and on the Swiss Federal Railway, the piston rods, when made new and when under repair, are ground true; on the Swedish State Railway and on the St. Gothard Railway they are then polished in order to obtain a good smooth surface; on the other railway they are not ground, but only rubbed down with emery.

6. *The use of superheated-steam locomotives.* — Particulars about the number, date of introduction and intended increase in the use of superheated-steam locomotives.

The table shows that after the first trials made on the Prussian-Hessian State Railway from 1897 to 1902, this railway ordered a considerable number of superheated-steam locomotives in 1902; in consequence of the good results obtained with these locomotives, the other railways, from 1905 onwards, decided to introduce them and to extend their use still further.

7. *Superheated-steam compound locomotives.* — The Baden State Railway uses superheated-steam compound locomotives extensively; they are also used by the Bavarian State Railway, the Saxon State

*

Railway, the Wurtemberg State Railway, the Swiss Federal Railway and the St. Gothard Railway; and the high-pressure steam is in all cases superheated before it enters the cylinder. A larger number of such locomotives is on order for these railways and also for the Alsace-Lorraine Railway. In no case is the low-pressure steam superheated, or both the low-pressure and the high-pressure.

Index number.	Railway.	Superheated-steam locomotives.			
		Year of introduction.	In use in 1908.	Being built for 1909.	Remarks.
1	Alsace-Lorraine Railway	...	1	8	3/8 coupled four-cylinder express locomotives.
2	Baden State Railway	1907	13 (3 Schmidt, smoke tube. 10 Clench.)	12 (Schmidt).	More are going to be ordered. System not yet decided on.
3	Bavarian State Railway	1908	72 (Schmidt, smoke tube.)	47	
4	Oldenburg State Railway	...	...	...	
5	Prussian-Hessian State Railway	1897 (Since 1902 a large number).	1317 (520 Schmidt, smoke box. 784 — — tube. 12 Pielock.)	491 (482 Schmidt. 9 Pielock.)	
6	Saxon State Railway	1905	54 (Schmidt.)	38	
7	Wurtemberg State Railway	1907	2	22	
8	Danish State Railway	...	...	10	
9	Dutch State Railway	...	...	...	
10	— Railway Company	1907	7 (Schmidt, smoke tube).	7	
11	Luxemburg Prinz-Heinrich Railway	...	...	...	
12	Norwegian State Railway	...	...	2	
13	Stockholm-Rimbö Railway	1907	1 (Pielock).	...	
14	Swedish State Railway	1906	37 (Schmidt) and Clench as an experiment	43	
15	Swiss Federal Railway	1905	44 (Schmidt).	21	
16	St. Gothard Railway	1904	23 (6 Pielock. 16 Clench. 1 Schmidt.)	...	
17	Rhetian Railway	1906	8 (Schmidt, smoke tube.)	3	

The Swedish State Railway has fitted several compound locomotives with superheaters of the Clench type, and obtains steam heated to 240° C. (454° Fahr.) but it is not satisfied with the results obtained.

The Prussian-Hessian State Railway on the contrary has not yet used superheated steam for compound locomotives, but only for twin locomotives. As an experiment, steam driers of the Schmidt and Pielock types are now being fitted to compound locomotives, but no results have as yet been obtained. It is intended

to make trials with four-cylinder superheated-steam compound locomotives.

8. *Effect of superheated steam.* — Experiments for determining the effect of superheated-steam locomotives have only been made, on the larger scale, by the Prussian-Hessian State Railway; they are fully described in the works of Robert Garbe, which have already been quoted. None of the other administrations have yet finished their experiments on the subject.

The Prussian-Hessian State Railway reports on the subject as follows :

Experiments for determining the effect of superheated steam have been made several times. The experiments are not absolutely unobjectionable, as the administration of the Prussian-Hessian State Railway has it is true wet-steam and saturated-steam locomotives of the same kind, but not of the same power. The experiments also extend at present only over a comparatively-short period, up to three months.

The results obtained depend chiefly on whether the locomotives are worked to their full power. This is so in the case of the Berlin suburban traffic; during the three months of trial an average coal economy of 15 per cent and an average water economy of 25 per cent were observed as compared with wet-steam locomotives.

The superheated-steam locomotives used for express trains also show very appreciable economies; thus for instance in the district of the Elberfeld directorate the $^2/_4$ superheated-steam locomotive (S. 4) showed a coal economy of 9 per cent as comparated with the similar wet-steam locomotive.

In the district of the Hanover directorate the comparison made January-March 1908 between the $^2/_4$ express-superheated-steam locomotive (S. 6) and the $^2/_5$ four-cylinder express wet-steam compound locomotive (S. 7) showed a coal economy of 7·8 per cent and a water economy of 15·2 per cent in favour of the former.

In the Magdeburg district, a comparison of the same classes showed a coal economy of 6·6 per cent and a water economy of 16·9 per cent in favour of the former.

In the Saarbrucken district, the $^4/_4$ goods superheated-steam locomotives, compared with the $^4/_4$ goods wet-steam compound locomotive, showed a coal economy of 6·3 per cent and a water economy of 8·7 per cent, the same amount of work being done. In the Frankfort district, a comparison of the same classes showed a coal economy of 12 per cent and a water economy of 29 per cent in favour of the former.

Sections of line on which there are many short and steep gradients do not enable the superheated-steam locomotive to be utilized well, if the fully-loaded trains, in spite of the use of such locomotives, still require double heading and if the goods traffic on such sections is irregular, so that heavy trains which require double heading alternate with smaller trains which are not fully loaded.

The superheated steam locomotives are more powerful than similar wet-steam locomotives, as the use of the superheated steam makes it possible to have larger cylinders without increasing the boiler pressure. In consequence, double heading is materially reduced and economies made in locomotives and locomotive

crews, in addition to the coal economies. It also makes it easier to run and to make a better and quicker start.

The highest temperature of the steam obtained in the heavy express service is 350° C. (662° Fahr.), and in the suburban service about 300° C. (572° Fahr.).

The ratio of the weight, in running order, of the superheated steam locomotive to that of the wet-steam locomotive is smaller than the ratio between the powers given. Thus for the same amount of power, the superheated steam locomotive could be lighter. Thus for instance the ratio of the weight is $S_4 : S_3 = 1 : 0{\cdot}93$, while the ratio of the powers is $S_4 : S_3 = 1 : 0{\cdot}75$.

As the power of the locomotive depends *inter alia* on the adhesive weight, a reduction in the weight will also result in a reduction in the power. The administration of the Prussian-Hessian State Railway has accordingly increased the wheel-load of the locomotives to the highest limit admissible, namely 8 tons (7·84 English tons), so as to obtain as much power as possible.

The Swiss Federal Railway states that the regular traffic returns show that the superheated steam locomotive is superior to the compound locomotive, as regards economy of working, if the great tractive force of the superheated steam locomotive, which results from the large size of the cylinders, can be utilized in the service. It states that the highest temperature of the steam when the locomotive is giving its full power is from 320 to 350° C. (608 to 662° Fahr.), records that for the same weight the superheated steam locomotives is more powerful than the wet-steam locomotive, and intends, in the case of new locomotives, to give the superheated steam locomotive a larger boiler, as has already been done in the case of the boilers supplied towards the end of 1908 for the $^3/_4$ passenger locomotive, which as compared with the wet-steam locomotives hitherto built was made larger without increase of weight.

The St. Gothard Railway finds that the superheated steam locomotive saves both coal and water, and states that it is more powerful than wet-steam locomotives of the same class.

It obtained with the different superheaters the following temperatures of steam, measured in the dome when the locomotives were doing their normal work and were running up gradients of 26 per mil :

Pielock superheater	275° C. (527° Fahr) passenger train.
– —	290° C. (554° —) express train.
Schmidt —	330° C. (626° —) passenger train.
— —	350° C. (662° —) express train.
Clench —	270° C. (518° —) — —

The Swedish State Railway gives the coal economy of the superheated steam locomotive as 46·5 to 47·1 per cent, and the highest temperature as 320° C. (608° Fahr.); but this very high figure for the coal economy is probably due to the fact that during the trial runs in question, the wet-steam locomotive, as compared with the superheated steam locomotive which is of itself already more powerful,

was already working under unfavourable conditions by having to haul the same heavy load.

The Dutch Railway Company states that the superheated steam locomotives used in the ordinary service show a water economy of 30 per cent and a coal economy of 20 per cent, and increase of power of 20 per cent and a maximum temperature of 350° C. (662° Fahr.).

The Bavarian State Railway found the highest-attainable temperatures to be 300 to 350° C. (572 to 662° Fahr.); the Wurtemberg State Railway obtained 340° C. (644° Fahr.) with passenger trains and 370° C. (398° Fahr.) when the locomotives were working at their full power and hauling express trains.

All the administrations, in introducing superheated steam, had as their object not a reduced weight for the same power as compared with the wet-steam locomotive, but to obtain with the same weight a greater power than could be obtained from wet-steam locomotives. The attendant advantages of being able to haul heavier trains and of reducing double heading, always so onerous, and of saving coal and water when the same amount of power is utilized, more than compensate for the greater prime cost of the superheated-steam locomotives.

Moreover, of late the weight of the locomotives has everywhere been increased up to the maximum wheel-loads admissible in the different districts (standard in Germany, 8 tons [7·84 English tons]), and has thus made available a greater adhesive weight for the superheated-steam locomotive with its larger cylinders and greater thermal efficiency, so as to obtain as powerful a locomotive as possible. In doing this, the advantage still remains with the superheated-steam locomotive as compared with the wet-steam locomotive, as the increase in power is greater than the increase in weight. In the instance of the $^2/_4$ express superheated-steam locomotives of the Prussian-Hessian State Railway, an increase of 7·5 per cent in the weight of the locomotive corresponds to an increase of 33 per cent in the power, and the per unit weight of locomotive is increased by 19·5 per cent in round figures, if we compare the two kinds of locomotives.

A table showing the chief dimensions of the superheated-steam and wet-steam locomotives compared is given in appendix I.

9. *Measurement of the superheat. Steam pressure. Ratio of total heating surface to superheating surface.* — The superheat is measured in every case either in the valve chest or immediately before it, by means of the distance pyrometer made by Steinle & Hartung, of Quedlinburg; the Prussian-Hessian State Railway and the St. Gothard Railway also use the distance pyrometer made by Schäffer & Budenberg, of Buckau. It is advisable to pay special attention to these instruments, which are to guide the locomotive staff in their treatment of the engine; the instruments should often be checked, and in fixing them in the spaces whose temperature is to be measured, care has to be taken that the mercury container is in its proper position, as an incorrect position may produce errors, which in some cases amounted to 50° C. (90° Fahr.), and were corrected by adjusting the dipper.

The fall of pressure between the boiler and the valve chest is, on the average,

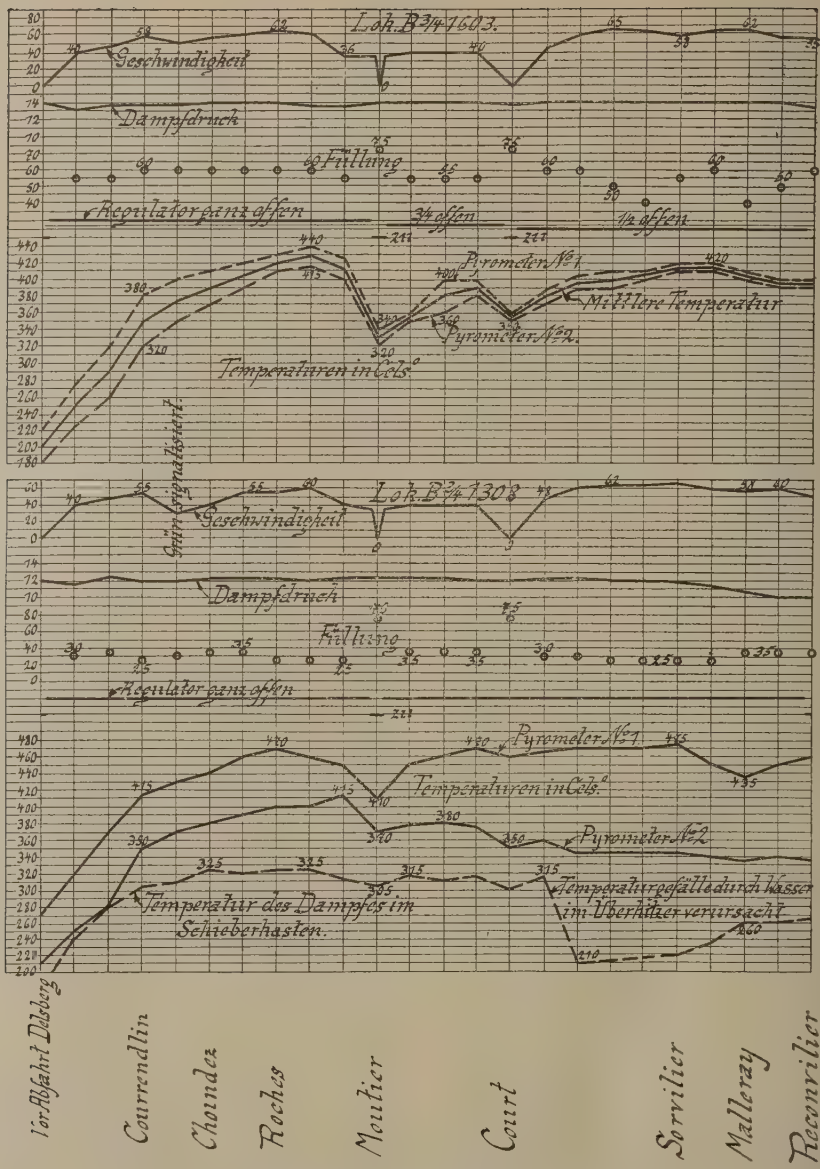
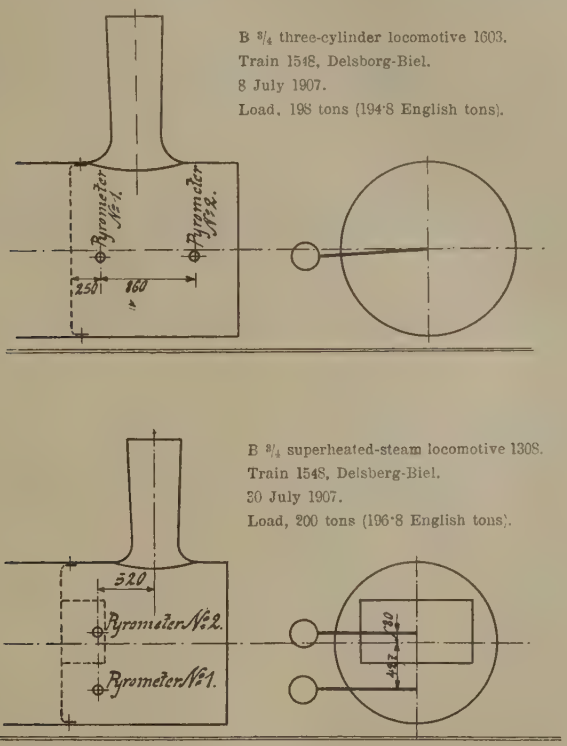


Fig. 68. — Comparative measurements of the temperatures of the hot gases in the smoke-boxes of locomotives B 3/4 1603 and B 3/4 1308.

Explanation of German terms : Geschwindigkeit = Speed. — Dampfdruck = Pressure of steam. — Füllung = Cut-off. — Regulator ganz offen = Regulator full open. — 3/4 Offen = 3/4 open. — 1/2 Offen = 1/2 open. — Pyrometer N° 1 = Pyrometer No. 1. — Temperaturen in Cels° = Temperatures in degrees centigrade. — Pyrometer N° 2 = Pyrometer No. 2. — Grün signalisiert = Green signal. — Mittlere Temperatur = Average temperature. — Temperatur des Dampfes im Schieberkasten = Temperature of steam in valve chest. — Temperaturgefälle durch Wasser im Ueberhitzer verursacht = Drop of temperature caused by water in superheater.

0·5 atmosphere when the locomotive is working at full power, and varies between 0·3 and 0·8 atmosphere, according to cut-off and speed. The distance pressure-gauge for reading in the cab the pressure in the valve chests has given good results.



N. B. — The pyrometer was checked in a paraffin bath after each trial.

Fig. 69. — Double-heading on 8 and 30 July on the Moutiers-Court section by locomotive 6506.

The pressure of the steam entering the cylinders is according to the measurements made on the Prussian-Hessian State Railway lighter with wet-steam locomotives having the same boiler pressure, same cut-off and same speed with the regulator full open. The difference amounts to about 0·4 to 0·6 atmosphere.

With increased superheat the power of the locomotive also increases, and the coal and water economies increase according to this administration in the same direct ratio. Further particulars as to the relations between degree of superheat, additional power and economy obtained are not given.

The ratio of total heating surface to superheating surface is fixed to suit the power the individual classes of locomotives are required to supply; it is not definitely fixed and is on the average about 4·5 : 1.

The use of superheated steam has made it possible to retain the working pressure of 12 atmospheres, while the contrary was the case with wet steam, as the working pressures of such locomotives had to be raised to 14 and 16 atmospheres when greater power was required. Almost all the superheated-steam locomotives have a working pressure of 12 atmospheres, the idea being to utilize the advantages of superheated steam with the simple arrangement of the locomotive as a twin engine, with larger boilers and larger cylinders. Recently however, higher working pressures, up to 16 atmospheres, have also been tried with superheated steam, in order to combine the advantages already obtained with those of compounding, and to be able to use on a large scale the balanced four-cylinder engine, which is favoured by some administrations. The matter is a present in the experimental stage and much interest is shown in it, more especially by the Saxon State Railway, the Bavarian State Railway, the Wurtemberg State Railway, the Swiss Federal Railway and the Alsace-Lorraine Railway.

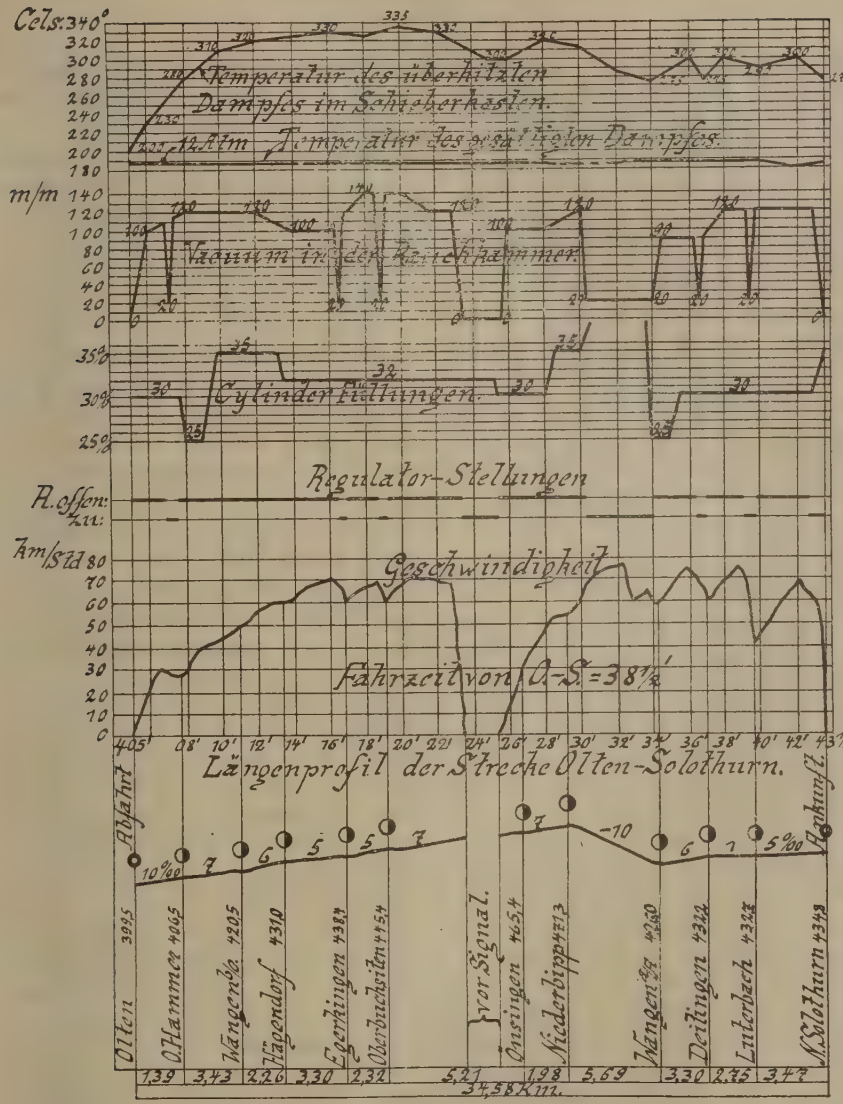
The dimensions of the cylinders in the more recent superheated-steam locomotives are in most cases increased, as compared with wet-steam locomotives, by about 20 to 25 per cent so far as the pistons are concerned, but a considerable number of locomotives are in use which did not have the cylinders altered when they were built as superheated-steam locomotives, or else were converted into such by the addition of superheaters to existing locomotives.

9bis. *Measurements of temperature.* — Simultaneous measurements of the temperature of the hot gases at various points of the fire-box, the smoke tubes or flue tubes and the smoke-box, as compared with the degrees of superheat obtained at given pressures, have not been made; the Swiss Federal Railway however, has supplied a diagram (see figs. 68 and 69), representing the results of trials of two locomotives, a $^3/_4$ three-cylinder passenger locomotive and a $^3/_4$ passenger superheated-steam locomotive; the temperatures of the smoke-box and the valve chest and the pressures are recorded. Figure 70 is a second diagram representing the trials of a similar $^3/_4$ superheated-steam locomotive of the Swiss Federal Railway.

10. *Saving of coal. Increase of power. Results of trials to show the relation of the advantages obtained in practice to those deduced theoretically.* — The Saxon State Railway considers that the coal economy is but small on goods locomotives, but greater on express locomotives; the limited and incomplete observations made leads it to estimate this saving at about 6 per cent.

The Swiss Federal Railway states that under the most favourable conditions (heavy trains, full utilization of the power), the saving of fuel, according to the working results of five months, amounts to 10 per cent in the case of its $^4/_5$ goods superheated-steam locomotives and to 5 per cent in that of its $^3/_5$ four-cylinder

Train 76. Weight of wagons, 334 tons (328·7 Engl. tons).



Water consumption : Olten-Solothurn, 3·8 cubic metres (134·2 cubic feet); but little residue.
Weather : light rain, strong head wind.

Fig. 70. — Trial run with B 3/4 superheated-steam locomotive No. 1305, with Schmidt smoke-tube superheater, on 10 April 1907, from Otten to Solothurn.

Explanation of German terms : Cels = Centigrade. — R. offen = Regulator open. — R. zu = Regulator closed. — Km. Std. = Kilometres per hour. — m/m = Millimetres of water. — Temperatur des überhitzten Dampfes im Schieberkasten = Temperature of superheated steam in valve chest. — Atm. = Atmospheres. — Temperatur des gesättigten Dampfes = Temperature of saturated steam. — Vacuum in der Rauchkammer = Vacuum in smoke-box. — Cylinder Füllungen = Cut-off. — Regulator-Stellungen = Position of regulator. — Geschwindigkeit = Speed. — Abfahrt = Departure. — Ankunft = Arrival. — Längenprofil der Strecke Olten Solothurn = Profile of the Olten-Solothurn section. — Fahrzeit von O. S. = 38 ½' = Time required from Olten to Solothurn, 38 ½ minutes.

express superheated-steam compound locomotives, as compared with the $^3/_5$ four-cylinder express wet-steam compound locomotives.

The Rhetian Railway found that during the year 1907 a saving of 6 to 9 per cent was effected by the superheated-steam locomotives.

The Baden State Railway finds that as a rule the boiler output is increased by about 20 to 25 per cent by the use of superheated steam and that the tractive power is increased to the same extent. The experiments on the coal consumption have not yet been concluded.

The Dutch Railway Company obtains a saving of 20 per cent in round figures; the Swedish State Railway even states that it has effected a saving of 46·5 to 47·1 per cent.

The Prussian-Hessian State Railway, according to the statements made under question 8-*a*, has obtained the following savings in coal : Berlin suburban service, with tank locomotives, 15 per cent; Elberfeld district, with $^2/_4$ express locomotives, 9 per cent; Hanover district, with $^2/_4$ superheated-steam express locomotives as compared with $^2/_5$ four-cylinder wet-steam express locomotives, 7·8 per cent; Magdeburg district, with the same locomotives as in the Hanover district, 6·6 per cent; Saarbrucken district, goods traffic, with $^4/_4$ superheated-steam locomotives as compared with $^4/_4$ wet-steam compound locomotives, 6·3 per cent; and in the Frankfurt district, with locomotives of the same class, 12 per cent.

The Wurtemberg State Railway states that, other conditions being equal, the superheated-steam locomotives can haul greater loads while consuming a little less fuel; that accordingly they have a greater thermal efficiency than similar wet-steam compound locomotives of the same size. As regards steam condensation in the cylinders, this is observed to be much less in the case of the superheated-steam locomotive.

The Prussian-Hessian State Railway expresses itself as follows :

The theoretically-deduced advantages of the superheated-steam locomotives are the small condensation and the small fall of pressure between boiler and cylinder, so that the boiler output is improved.

Condensation in the superheated-steam locomotive is much reduced, as the steam enters the cylinders at high temperature and pressure. Hence it is possible to have larger cylinders, and this makes the locomotive more powerful; this is of particular advantage when starting trains.

As compared with the wet-steam boiler, the economy, the power and the heat utilization of the superheated-steam boiler rises with the power, up to a definite limit. The superheated-steam locomotive is hence advantageous for heavy work, for it overcomes excessive loads more easily, should such occur.

The figures for the savings are given in the annexed table; they show that in the ordinary service and with suitable train loads the coal saving obtained by means of the superheated-steam locomotive amounts to about 8 to 10 per cent in the case of express and passenger trains and also to about 8 to 10 per cent in that of goods trains. Savings which exceed 15 per cent may be attributed to the wet-steam locomotives working under unfavourable conditions.

Apart from this, more detailed trials extending over longer periods of time have not been made or not yet been concluded, as regards the coal economy of the superheated steam locomotives as compared with the wet-steam twin and compound locomotives, taking into consideration the loads hauled, in the course of the ordinary service, over equal distances. It seems very desirable that such trials should be made on the large scale by the administrations concerned, so as to determine the economy of the increased power, per unit of coal and of steam used, realized in the course of ordinary traffic, and not merely under the special conditions obtaining when special trial runs are made.

Index number.	Administration.	Class of locomotive.	Economy of superheated-steam locomotive.			
			Coal, per cent.		Water, per cent.	
			On passenger and express trains.	On goods trains.	On passenger and express trains.	On goods trains.
	Prussian-Hessian State Railway:					
1	Berlin surburban traffic. . .	Tank locomotives.	15	...	25	...
2	Elberfeld directorate. . . .	$^2/_4$ express locomotives.	9	...	...	...
3	Hanover directorate	$^2/_4$ superheated-steam express locomotive. $^2/_5$ four-cylinder wet-steam compound locomotives.	7·8	...	15·2	...
4	Magdeburg directorate . . .	The same.	6·6	...	16·9	...
5	Saarbrucken directorate . .	$^4/_4$ goods superheated-steam locomotive. $^4/_4$ goods wet-steam compound locomotive.	...	6·3	...	8·7
6	Frankfurt directorate . . .	The same.	...	12	...	29
7	Saxon State Railway	Express locomotives.	About 6.	...	...	...
8	Ditto	Goods locomotives.	...	Slight.	...	...
9	Wurtemberg State Railway. .	...	...	...	Considerable.	...
10	Swiss Federal Railway . . .	$^3/_5$ four-cylinder express superheated-steam compouds locomotive. $^3/_5$ four-cylinder express superheated-steam compound locomotive.	5	...	...	...
11	Ditto	$^4/_5$ goods superheated-steam locomotive. $^4/_5$ superheated-steam compound locomotive.	...	10	...	...
12	Rhetian Railway	$^4/_5$ goods locomotives.	6-9	...	...	...
13	Dutch Railway Company. . .	$^2/_4$ express locomotives.	20	...	30	...
14	Swedish State Railway . . .	Passenger-train locomotives.	46-47	...	...	...

11. *Time required for repairs. Accessibility of the different parts of the superheater.* — The Prussian-Hessian State Railway gives the following report :

Taking into consideration that defects are most frequently found on the older locomotives, equipped with the smoke-box superheater, which are inferior and faulty as compared with the new locomotives equipped with the smoke-tube superheater, and that it was not yet possible to do away with all these faults, it is not yet possible to make any definite statements as to how much more time is required for repairs. The locomotives with the smoke-box superheater, according to the treatment they may have had, require probably up to 20 per cent more time for repairs than the similar wet-steam twin and compound locomotives, which however give less power. As regards locomotives with smoke-tube superheaters, the observations made in some districts show that there is no increase in this time, and in others that the increase is but small.

The time the superheated-steam locomotives are not in use has become increased owing to the need of periodically examining the pistons and the valve gear; this is not necessary in the case of the wet-steam locomotive. As yet it has not been found that more time has been required for the maintenance of the packings.

The service, the maintenance and the repair of the superheated-steam locomotives were influenced very adversely, particularly at first, by the fact that the locomotive crews and the employees at the locomotive sheds and workshops did not understand these locomotives properly; and also by the fact that the facilities for the careful treatment which the superheated-steam locomotive absolutely requires were not everywhere available. The time required for repairs is also adversely influenced by the circumstance that in order to avoid any increase in the axle-loads the dimensions of some the parts were kept as small as possible, and that consequently repairs (broken framing, loose cylinders) were more frequently necessary.

The older types of Pielock superheaters require a longer time for repairs, because the tubes soon rust through. No experience is yet available as regards the newer type.

The annual cost for repair and maintenance of the superheating equipment may amount up to 200 marks (£10) in the case of the smoke-box superheater. Sufficient results have not yet been obtained with the smoke-tube superheater, but the cost of repair is certainly considerably less.

In the case of the smoke-box superheaters, the renewal and the maintenance of the roof plates and of the front walls often give rise to considerable difficulty, as they often warp and are then no longer tight. Cracks are also observed more frequently in the flue tubes of these locomotives at the junctions with the copper tube-plate; hence protective copper or iron ferrules or rings of angle section had to be put in.

No troubles of any kind have as yet turned up in the case of the smoke-tube superheater.

With the Pielock superheater, the operation of putting in or taking out smoke tubes is made more difficult by the four joints. At first, the superheater and that

part of the smoke tubes enclosed in it, were liable to rust; this has been reduced by an automatic contrivance for filling the superheater with water. More recently, trouble has arisen in some cases in consequence of the deposit of larger quantities of scale in front of the front plate of the superheater, which has caused some smoke tubes to collapse.

The smoke-box superheater is not conveniently accessible in case of repair. It is difficult to renew a single tube; it is generally necessary to take out adjoining tubes, which are still in good conditions, as well.

The smoke-tube superheater is sufficiently accessible in all its parts when the dampers have been removed. The Pielock superheater is quite inaccessible.

Excessive wear has, as a rule, not been observed at any of the superheater tubes in the Schmidt superheater. On the other hand, the flue tubes of the smoke-box superheater frequently require repair at the joint in the copper tube-plate.

Obstruction by particles of ash and soot, particularly at the bottom of the smoke-box, cannot wholly be avoided in the case of the smoke-box superheater even if very carefully cleaned and maintained. At such points burning is very liable to occur, the tubes becoming prematurely destroyed or weakened.

In the case of the smoke-tube superheater, the smoke-tubes may become blocked by improper treatment, if they are not thoroughly cleaned out by compressed air (not steam) after long runs. The quality of the coal used has a material influence on such blocking up. No signs of any special wear have been observed in the case of this superheater.

The smoke-tube superheater is preferred because it is very accessible, is of simple construction, gives a good superheat, is very reliable and is very easy to clean. Any damaged part can be replaced quickly and without much expense. Defects in tubes are easily discovered. Spare parts can be stored and obtained very quickly.

The Pielock superheater has the advantage that it can subsequently be added to existing boilers; it involves no special cost of cleaning. It is difficult to get the smoke tubes tight; leaky places are difficult to detect and difficult to repair. Tubes sometimes collapse. Leaks, which enable water to accumulate in the superheater, reduce its efficiency.

Distortions in the tube-plates in the case of the Schmidt smoke-tube superheater have not been observed.

All the other administrations state that they are as yet unable to draw any conclusions as to the time required for repair and what it costs, as the superheaters have been in use but a short time.

As regards the reliability and the accessibility of the different parts of the superheater, all the administrations speak in favour of the Schmidt smoke-tube superheater which is now preferred; they have not found any unusual wear or blocking up of the smoke tubes, provided that these are cleaned frequently and carefully. Special difficulties in the maintenance of the superheaters of the three designs, Schmidt smoke-tube, Pielock, Clench, have not arisen. The Saxon State Railway however condemns the use of asbestos for making the superheater joints, as it becomes dissolved by the condensed water, and replaces it by Klingerite; it also considers design *a* (see figs. 71 to 73),

with horizontal flanges, unsatisfactory and uses design *b*; this design, and design *c*, have of late also been introduced on other railways. The two latter designs have the flange vertical.

On the St. Gothard railway, the original design of the Pielock superheater did not prove wholly satisfactory, and an improved design is now used. Putting in and replacing the tubes in the Pielock and Clench superheaters is a difficulty both in the construction and in the maintenance, as they have to be expanded very carefully in the intermediate plates.

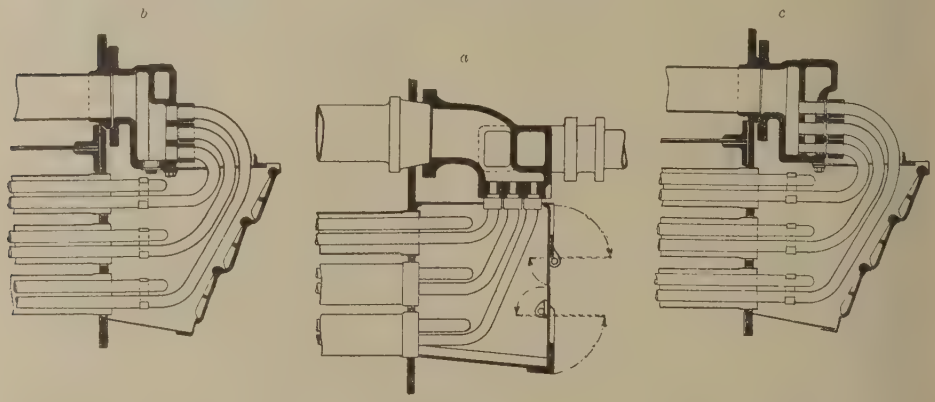
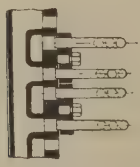


Fig. 71.



a) Connection of elements with horizontal plate.
b) Connection of elements with vertical plate with cast-in openings.
c) Connection of elements with vertical plate tubes entering.

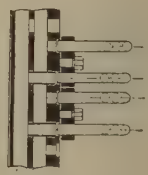


Fig. 72. Fig. 73.

Fig. 71 to 73.—Connection of the superheater elements with the collectors of the Schmidt smoke-tubes superheater.

The maintenance of the Schmidt smoke-box superheater has given trouble as defects arose at the flue tubes and at the superheater tubes during working; the accessibility of the latter also leaves much to be desired and this design is accordingly no longer used.

Distortions of the fire-box tube-plate between the bottom row of the large tubes and the top row of the small, in the case of the Schmidt smoke-tube superheater, have nowhere been observed.

12. *Lubrication.* — On the Prussian-Hessian State Railway the oiling of superheated-steam locomotives costs a little more, chiefly because the oil used with superheated steam is at a higher price. The four-cylinder wet-steam locomotive costs more for lubrication than the two-

Railway.	Firm supplying the oil.	Name given to oil.	Viscosity (according to Engler) at 100° C.	Flash point, in degrees centigrade.	Specific gravity at 20° C.	*Remarks.*
Prussian-Hessian State Railway.	Petroleum Raffinerie vorm. Aug. Korff, Brême.	Vaporine superheated steam oil. Mark H. D., dark.	5·4 to 6·7	311 to 358	0·902/0·916	...
Ditto.	Wilh. Hermann Schmidt, Magdebourg.	Special superheated-steam oil.	5·5	292	0·897	...
Ditto.	Emil Finke, Brême.	Vacuum cylinder oil. Lion brand, dark.	6·3	309 to 337	0·905	...
Ditto.	Stegnweit, Cologne s/Rh.	Superheated-steam oil. Mark I, light.	5·2	340	0·908	...
Ditto.	Schmidt, Dusseldorf.	Superheated-steam oil.	5·85	290	0·908	...
Ditto.	Korban, Breslau II.	Superheated-steam oil.	5·4	325	...	...
Ditto.	Janke & Gutberg, Berlin.	Superheated-steam oil.	...	322	at 50° C. = 0·881	...
Ditto.	F. Neuhoff, Dusseldorf.	Neudalm.	7·1 at 50° C. = 61·7	336	0·892	Is also used by the Wurtemberg State Railway. Loss by evaporation after heating to 350° C. for two hours, 9·2 per cent.
Ditto.	Urban & Lemm, Charlottenbourg.	Viscotol. Superheated-steam cylinder-oil.	7·2	305	0·902	...
Bavarian State Railway . .	...	...	Not below 3·0	280	at 15° C. 0·89/0·95	Loss of weight after heating to 200° C. for two hours, not greater than 0·2 per cent.
Saxon State Railway . . .	...	...	at 50° C. = 14·06 compared with crude rape-seed oil).	Not yet inflammable at 420° C.	0·902	Visible vapour formed at 190° C.
Swiss Federal Railway . .	...	...	4·5 4·9	332	0·894/0·904	Freezing point, 0° C. Acid content : traces, not exceeding 1/3 per cent.
St. Gothard Railway . . .	Vacuum-Oil Company.	Perfection Valve.	at 50° C. 25·6-33.	360	0·90/0·95	...

cylinder superheated-steam locomotive, which is of equal power.

The Dutch Railway Company states that the superheated-steam locomotives require 17 per cent more oil, the Swedish State Railway 26 per cent more oil, the Swiss Federal Railway a little more oil, the St. Gothard Railway and the Rhetian Railway a little less oil, than the wet-steam locomotives of the same power.

The oils used for the superheated-steam cylinders and piston valves, are pure mineral oils, of high flash-point. Greases and fixed oils, or a mixture of these and mineral oils, are not used.

Particulars about the viscosity, the flash-point, and the specific gravity are given in the annexed table, which also gives the names of the firms supplying these oils, in those cases in which the administrations have supplied this information.

Good results have generally been obtained with mechanically-operated oil presses and oil pumps of the following well-known designs : Ritter, Michalke, Dicker and Werneburg, Friedmann, Mildenburger and Mollerup. The Swiss Federal Railway sprays the oil, when running downhill with regulator closed, steam being led for the purpose by a special pipe to the valve chest. A hand-operated oil press is also provided as reserve. The Baden State Railway uses on each side of the locomotive a tenfold oil pump of the Friedmann design. The St. Gothard Railway sprays the oil by steams at the point of lubrication by means of Friedmann apparatus. Some sight-feed lubricators of the de Limon type, the oil being distributed at four points, are being used on the Prussian-Hessian State Railway as an experiment; no opinion can yet be given.

13. *Instructions to the staff.* — On all the railways, the locomotive crews and the men in the workshops received special instruction, given by the workshop and traffic officials, in the treatment and handling of the superheated-steam locomotive; special working regulations are issued containing detailed descriptions and drawings, and models of the different superheating arrangements are also supplied. A strict supervision is moreover exercised over the proper observance of the regulations issued, both in actual working as well as when the locomotives are at the sheds and chief repair shops.

The regulations issued on the Prussian-Hessian State Railway are reproduced in appendix II. The regulations issued by the other administrations contain very much the same.

No administration gives any information as to any accidents resulting from the introduction of superheated steam.

14. *Extended use of superheated steam.* — The different administrations express the following opinions :

Prussian-Hessian State Railways. — The superheated-steam locomotives are to be preferred to the wet-steam locomotives in all those cases in which they can work at full power over long distances without having to stop frequently. They are intended for heavy work and show considerable coal and water economies as compared with wet-steam locomotives. Further savings are effected by reducing double heading.

The use of superheated-steam locomotives can be recommended for the heavy express, passenger-train and goods-train services.

With lighter trains, with frequent stops, for which the existing wet-steam locomotives suffice, the advantages which heavier superheated-steam locomotives offer, would be counterbalanced by the greater cost of maintenance and the greater initial cost.

Superheated-steam locomotives are accordingly not yet provided on the Prussian-Hessian Railway for light services, as enough wet-steam locomotives are available.

Locomotives equipped with the Schmidt superheater cannot be recommended for shunting services, as the superheat does not provide sufficiently-superheated steam when short runs are made.

Baden State Railway. — Experience is as yet too short to allow this question to be answered decisively.

Bavarian State Railway. — The advantages of superheated steam are recognized. Superheated steam will gradually be introduced on all the locomotives which have to make long runs without stopping.

Saxon State Railway. — A conclusive opinion is not yet available, but it appears that superheated-steam twin locomotives are superior as express locomotives, which are to attain very high speeds. Further experience is required before it can be decided when in the case of the goods service wet-steam compound locomotives are to be preferred to superheated-steam compound and twin locomotives.

Wurtemberg State Railway. — The results that have been by now obtained in practice clearly show that the superheated-steam locomotive is superior to the wet-steam compound locomotive of otherwise the same construction; for it shows a somewhat smaller coal consumption and a materially smaller water consumption while giving greater power. The advantages of the superheated-steam locomotives are recognized in the first place for express and passenger trains. According to the results obtained up to the present, superheated steam is specially suitable for express and goods locomotives doing heavy work; but it is also suitable for tank locomotives which are to haul heavy passenger trains, on account of the great saving in water.

Dutch Railway Company. — The advantages of superheated steam are fully recognized and the use of superheated steam seems very advisable.

Swedish State Railway. — The opinnion is that the superheated-steam locomotive as compared with the wet-steam locomotive has the advantage of working very economically, and all the locomotives built after 1906 were equipped with superheaters. These include locomotives for heavy express trains as well as for heavy goods trains and the very heavy iron-ore trains.

Stockholm-Rimbö Railway. — No expression of opinion.

Swiss Federal Railway. — Advantages are recognized, particularly if the tractive force of the locomotive can be fully utilized in the service. According to the results so far obtained, the superheated-steam twin locomotive is very suitable for heavy trains not running at high speeds. The twin system does not suffice for express trains proper, as soon as cy-

linders of large dimensions become necessary. It is then better to use four-cylinder locomotives.

St. Gothard Railway. — The advantages of superheated-steam locomotives are recognized. Their use is recommended, in the form of twin locomotives for heavy goods trains and in that of four-cylinder compound locomotives for heavy express trains.

Rhetian Railway. — The advantages are recognized and the use of superheated steam is recommended for all classes of locomotives which are used exclusively for the line service.

Supplement to VI-B-b-2.

Valve gear for superheated steam. — The Prussian-Hessian State Railway supplies supplementary information about the results obtained recently (1909) during the trial runs made with the superheated-steam locomotives of new type designed by Professor Stumpf of Charlottenburg; these trials runs were made during the summer of 1909 with two of these locomotives.

The two goods locomotives Nos. 4825 and 4826 Frankfort were delivered in January 1909; they are superheated-steam locomotives with eight wheels, all coupled, and are equipped with Heusinger-Stumpf valve gear and with Stumpf cylinders. The characteristic feature of locomotives of this design is the application of the parallel-flow principle (avoiding transference of heat from the hot surfaces of admission to the cold exhaust steam) to the engine of the locomotive; the inlet valve of Stumpf design is operated by the usual Heusinger link motion and there is a long port in the direction of flow of the steam and a wide piston (see fig. 74).

The inlet valves were adjusted by the builders (the "Vulkan" works) in the cold; they were afterwards readjusted by means of diagrams taken with the engine hot. The trial runs then went off well and without trouble. The locomotive ran remarkably smoothly, in spite of the large reciprocating masses.

A train weighing 1,010 tons (994 English tons) (118 axles) was hauled over the section Grunewald-Belzig, and one weighing 1,010 tons (985 English tons) (116 axles) over the section Grunewald-Nedlitz and back. In the service schedule, the load for the $^1/_4$ goods superheated-steam locomotives (class G. 8) specified for the section Bruck-Belzig is only 900 tons (886 English tons) and for the section Belzig-Wiesenburg only 840 tons (827 English tons). The weather was unfavourable when the train was hauled to Nedlitz. When Bruck station had been passed, some rain and snow began to fall, and in consequence a good deal of slipping took place, in spite of continual sanding. (In dry weather, with rails that are not slippery, the adhesive weight of a locomotive of class G. 8 is already fully utilized when hauling a train of over 1,000 tons (984 English tons) on this section, where there is an up-gradient of 6·7 per mil. The boiler and the engine could both have given more power. The train, in spite of the slipping, was hauled very well, and the ascent from Belzig, to Wiesenburg took 8 minutes less than schedule time. Particulars of the trial are given in the annexed table, and the performance is compared with that of the wet-steam locomotive 4559 Cologne (eight wheels), all coupled;

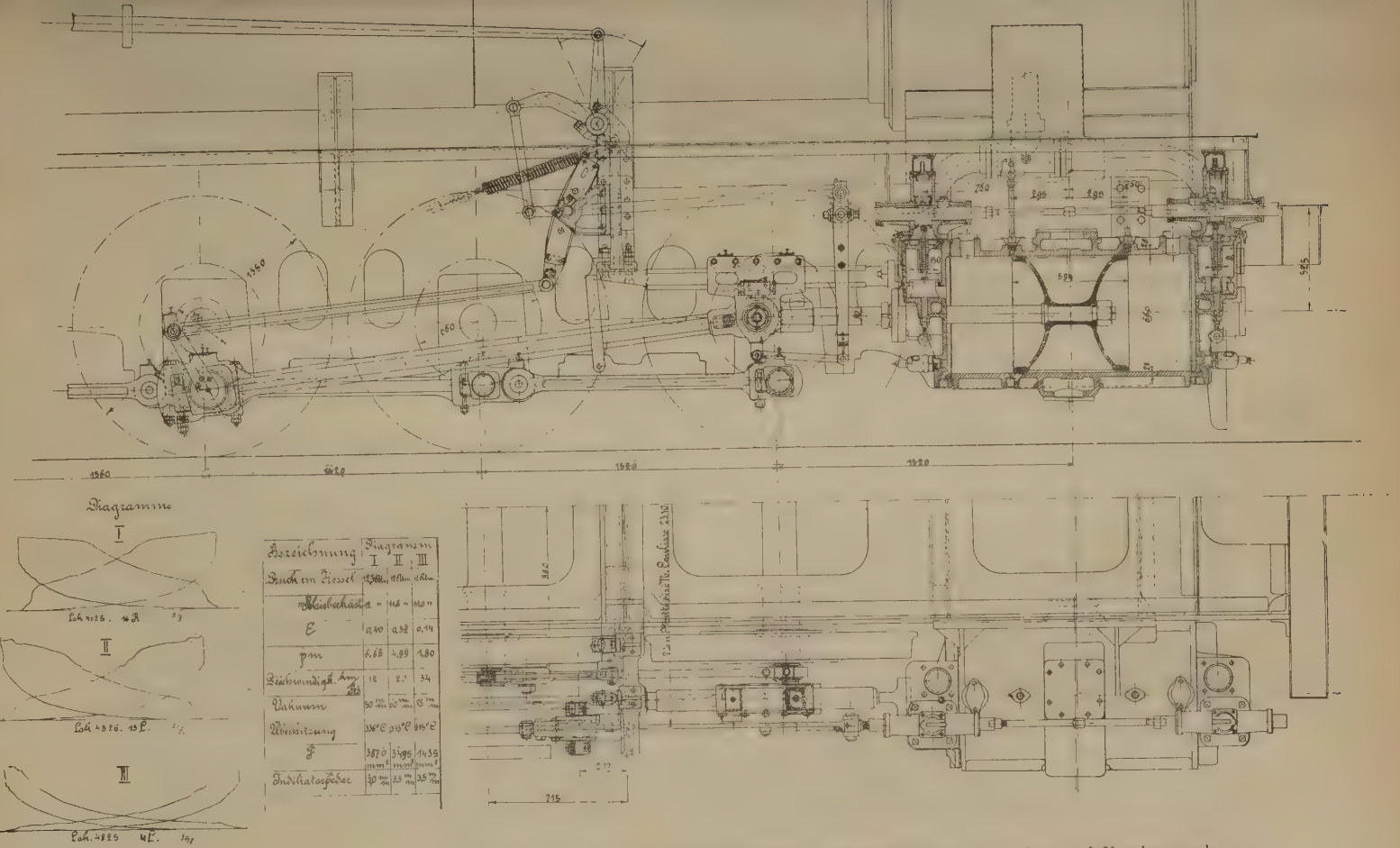


Fig. 74. — 4/4 superheated-seam locomotive for goods trains, with Schmidt smoke-tube superheater, Stumpf cylinders, and Heusinger valve gear with the Stumpf arrangement of valve. Prussian-Hessian State Railway.

Explanation of German terms : Diagramms = Diagrams. — Bezeichnung = Item. — Druck im Kessel = Pressure in boiler. — Druck im Schieberkast. = Pressure in valve chest. Geschwindigkeit km/Std = Speed, in kilometres per hour. — Vakuum = Vacuum. — Ueberhitzung = Superheat. — Indikatorfeder = Indicator spring.

heating surface, 200 square metres (2,152 86 square feet); weight 60 tons (59 English tons), which was also used for hauling a train weighing 1,001 tons (985 English tons), but on the materially-easier section Grunewald-Belzig and back.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Run number.	Locomotive number.	Section.	Length of section, in kilometres.	Train of number of axles.	Train of weight, in tons.	Ton-kilometres.	Net time required, in minutes.	Consumption of coal, in kilograms.	Consumption of coal, per 1,000 ton-kilometres, in kilograms.	Consumption of water, total, in kilograms.	Consumption of water, per 1,000 ton-kilometres, in kilograms.	Coefficient of evaporation.	Boiler, steam generated per hour, per square metre of heating surface, in kilograms.	Coal consumed per hour, per square metre of grate area, in kilograms.
I	4825	Grunewald-Nedlitz and back.	181·4	116	1,001	181,581	400	4,300	23·67	24,500	135	5·70	26·2	274
II	Frankfurt.	Grunewald-Belzig and back.	126·0	118	1,010	126,630	243 1/2	2,550	20·14	16,000	126	6·28	28·2	268
III	4559 Cologne.	Grunewald-Belzig and back.	126·0	116	1,001	126,126	226	3,400	26·90	25,300	200	7·44	33·6	350

The loads of 1,001 tons (985 English tons) hauled over the experimental sections are, as may be gathered from the schedule loads mentioned, rather greater than the economically most suitable loads for a locomotive of class G 8; the consumptions determined in both cases can hence not be considered as the lowest attainable.

It may be mentioned that according to the records the time required for the uphill section Bruck-Belzig (with locomotive 4825 Frankfort, with Stumpf valve gear) was thirty-four minutes in run II and thirty-six minutes in run III (locomotive 4559 Cologne). The difference in the total net time, in which locomotive 4559 Cologne is superior to locomotive 4825 Frankfort, consequently was only produced while running on the level sections. Locomotive 4825 Frankfort could thus also without difficulty have covered the distance in the shorter time. The less favourable coal and water consumption in run I is due to the fact that on the section Belzig-Wiesenburg on the out journey, and on the section Nedlitz-Wiesenburg on the return journey, the locomotive had to haul loads greater than those economically suitable, even more so than was the case during run II. The slipping mentioned above may also have contributed to the higher consumption.

Runs made with locomotive 4825 are represented graphically in figures 75 and 76. Figure 74 shows some characteristic diagrams obtained with these locomotives. The continuous high pressure in the valve chest, the continuous uniform compression and the remarkably

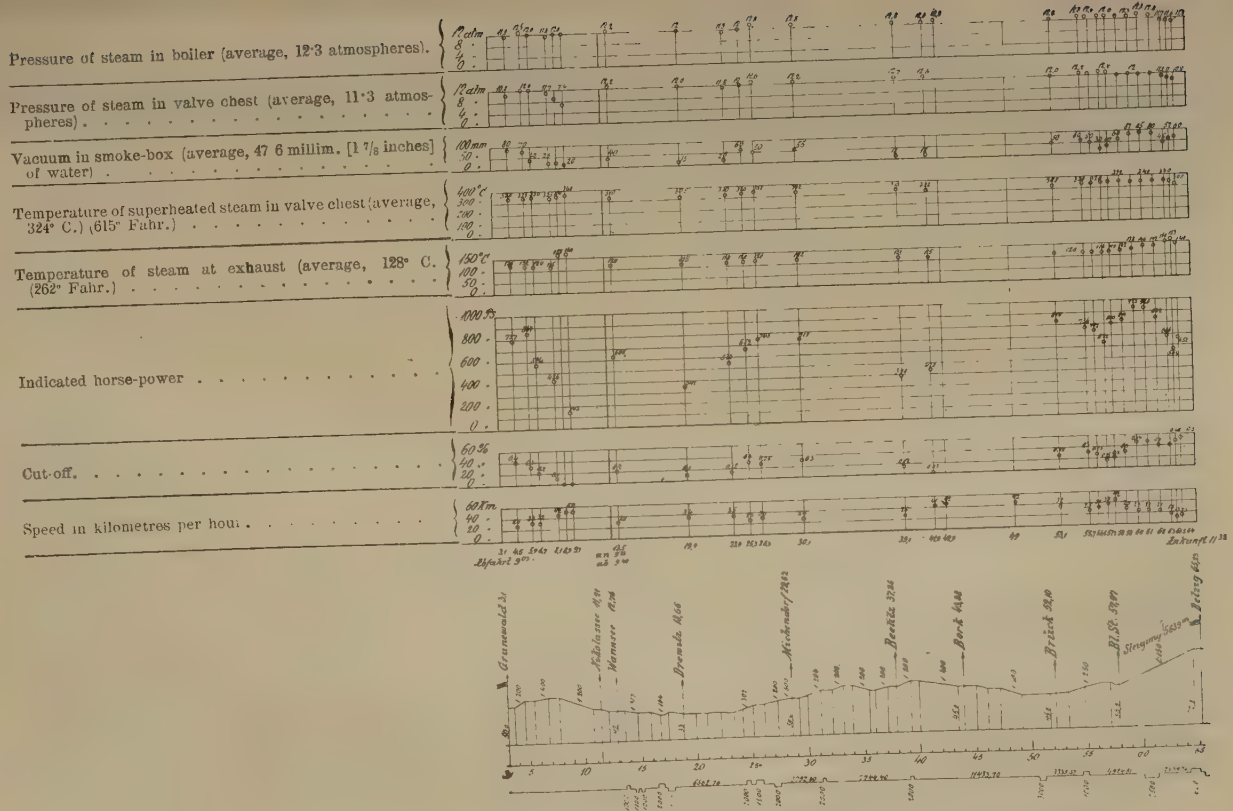


Fig. 75. — Trial run with 4/4 superheated-steam locomotive for goods trains, with Schmidt smoke-tube superheater, Heusinger-Stumpf valve gear and Stumpf cylinders. Prussian-Hessian State Railway.

Explanation of German terms : **Abfahrt** = Departure. — **Zukunft** = Arrival. — **Steigung** = Gradient.

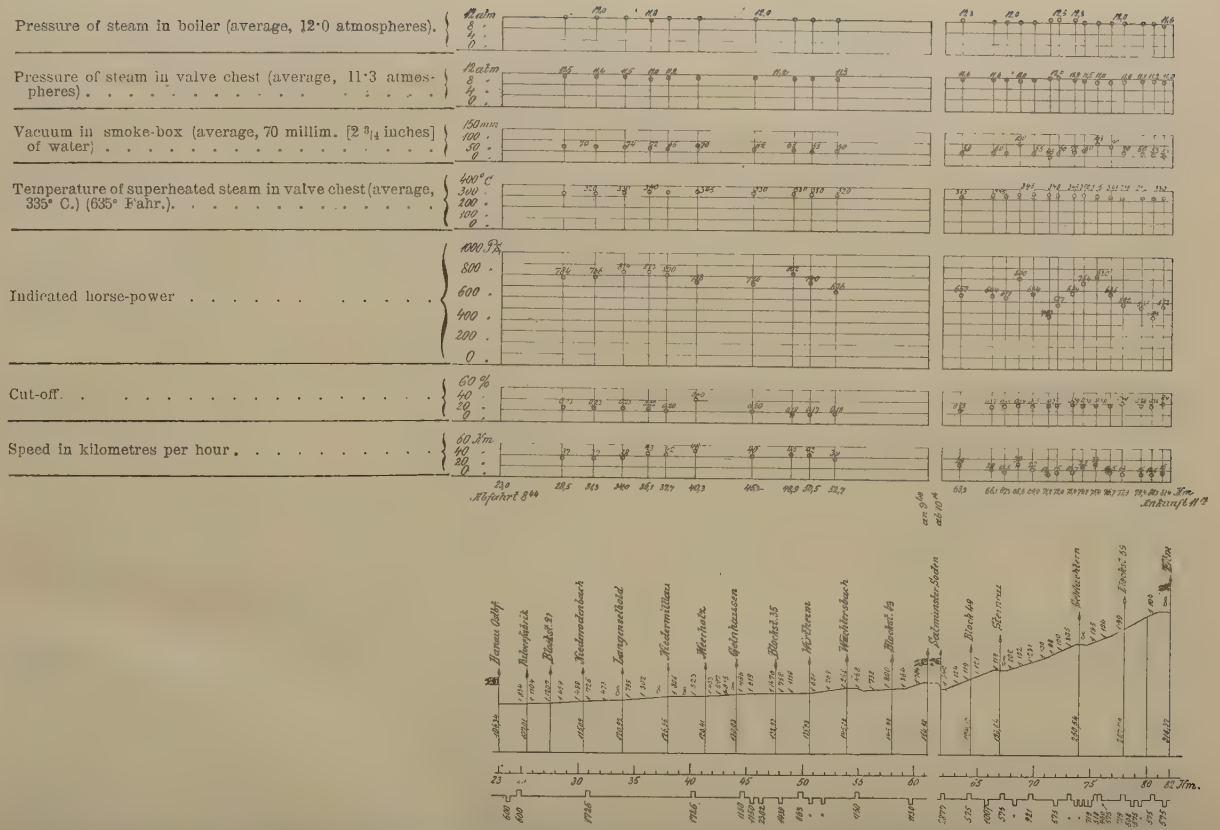


Fig. 76. — Trial run with 1/4 superheated-steam locomotive for goods trains, with Schmidt smoke-tube superheater, Heusinger-Stumpf valve gear and Stumpf cylinders. Prussian-Hessian State Railway.

Explanation of German terms : Abfahrt = Departure. — Zukunft = Arrival.

low vacuum are worth notice. The locomotive ran smoothly and well at all speeds and at all cut-offs. The clearance spaces amounted on the average to 51 litres (1·3008 cubic feet), or 30 per cent of the volume displaced by the piston. The comparatively low vacuum sufficed perfectly. The steam production was sufficient, even when the work was hardest, so that the boiler reserve was ample in spite of the excessive loads on the up gradients. The steam consumption must be described as remarkably low. The steam during run I on the uphill section Bruck-Wiesenburg was in spite of the excessive load only generated at the rate of 38 kilograms per square metre (7·78 lb. per square foot) of heating surface per hour. Cobbles from upper Silesia were used for firing. In consequence of the low vacuum the amount of cinders collected in the smoke-box was low.

No ejection of sparks could be observed, while running in the evening, although hard work was being done.

The exhausts, as the diagrams show, are well proportioned. No back pressure takes place at any speed or at any cut-off. In order to increase the flow of the hot gases through the smoke tubes and so increase the superheat which was at first a little low, the blast-pipe was placed about 50 millimetres (2 inches) higher. The superheat increased in consequence to about 330° C. (626° Fahr.) on the average.

The arrangement of the different details of the valve gear and their construction are very suitable; more especially it is possible, at any time and without loss of any time, to examine the valves and other parts and adjust any valve if required. It is also possible to take out any valve, after the corresponding rod has been removed, in a very short time. Any cutting or seizing of the rollers on their bearing or of the crank pins (a defect which has often been observed with the Lentz design) is not to be feared, as the rollers run in an oil bath. Any blowing away of the oil from the surfaces of the valve rod guides by steam passing through the labyrinth is impossible (contrary to the Lentz design) as the space between the labyrinth and the rod guides is in connexion with the outer air.

The position of the valves at the cylinder covers offers such advantages from the thermic point of view (the hottest points at which the steam is stored, are in conducting contact, only by the narrow packing edge, with the cylinder which leads away the heat to the frame and to outside), that the consideration of a somewhat easier construction of the piston if the valves are on the cylinder may be neglected, particularly as the wide Stumpf piston does not require careful observation in ordinary working.

A further advantage of having the valves at the cover consists in the very simple casting required for the cylinder, which consists merely of a tube with two flanges. Such a casting is very easy to make; but above all heat expansion will only be linear and hence not give rise to distortion and strains during casting and during subsequent use.

The middle rings of the piston, which transmit the weight of the piston to the body of the cylinder and keep the temperature between the two halves of the piston (as forming the boundaries of the compression space) as high as possible, to

prevent losses of cooling in the exhaust direction, have given satisfactory results thanks to proper provision of lubrication. Consequently there is no need for a piston rod with tail rod, with consequent trouble and loss at another stuffing box, in the front cover of the cylinder. The automatic cleaning of the cylinder, which has still to be mentioned, seems to make it unnecessary to examine the piston frequently, particularly as even a slight want of tightness of the piston is easily noticeable in consequence of the parallel flow, at the exhaust.

The compression-reducing appliance added to the cylinder, for keeping it free from water, is considered indispensable. Should the automatic double piston in the device become set, it appears doubtful whether the corresponding part of the cylinder would be kept free from water. The ordinary method of keeping the cylinders free from water should also suffice when the Stumpf valve gear is used.

The possibility of water-hammer action in the cylinder is already very small owing to the clearance space of 51 litres (1·3008 cubic feet) = 30 per cent. It is moreover reduced because the steam flows in a uniform direction (not reversing), in the direction in which gravity acts, so that any water carried over is ejected from the ports.

Before the construction of the locomotive with Stumpf valve gear, there were several points which were doubtful :

1° How the sudden short rush of the exhaust steam would act on the fire and to what extent the vacuum would be effected by the intervals between the emission of exhaust steam;

2° Whether the proposed design of piston with wide supporting surface would give good results in practice with steam which was highly superheated;

3° Whether the rather large reciprocating masses (the Stumpf piston with rod weighs 258 kilograms [421 lb.] as compared with the normal weight of 191 kilograms [569 lb.]) would at high speeds not cause unsteady running, or increased wear of the rod bearings.

The results obtained make it possible to state that these misgivings are baseless. The short exhaust produces all the vacuum required; the short rushes of steam produce rather too noisy an exhaust at present, but it will probably be possible to reduce this noise by modifying the shape of the exhaust port (allowing this to begin exhausting a little earlier) and allowing more space between the cylinder and the blast pipe. The peculiar pistons have in spite of their wide bearing surface given good results, as already stated, probably because the cylinder is comparatively cool in the middle and there is ample lubrication (at six points). The large reciprocating masses have not produced unsteady running or increased wear of the bearings, probably because the dead point is in a very favourable position, as it is influenced almost only by the kinetic energy of the masses, which depends on the rate at which the wheels turn Investigations as to the best position of the dead point and its influence on the running of the locomotive and on the wear of the bearings are at present being carried out, but are not yet completed.

These locomotives are at present already recognized to have the following advan-

tages : in consequence of the parallel flow of the steam a good thermal efficiency is obtained and therefore — a low consumption of steam. The cylinders are cleaned automatically. All the cylinders of the locomotives hitherto constructed form a sort of receptacle, out of which dirt of various kinds (particles of ash, residues, etc.) could only be removed by hand after taking off the covers. With the Stumpf design the steam at once sweeps out such dirt through the exhaust ports.

There is also an absence of the fundamental defect inherent in a common inlet and evhaust valve gear that the expansion, the exhaust lead, the compression and the admission lead are interdependent. The exhaust takes place, without special device, under the best conditions possible, without hardly any throttling, as the front cross-sections are very large. Any steam which leaks past in consequence of want of tightness in the valve gear, has not as hitherto the possibility of escaping out without doing any work. It must pass through the cylinders, doing work. As there are only two valves of suitable design which have to be operated by the link, which are kept closed by two weak springs, the back pressure on the reversing gear is so slight, that it is hardly necessary, while running, for the catch to engage. Everything makes it probable that maintenance during use will be very slight.

The ingenious pressure-equalizing device for running with regulator closed (see fig. 74; the inlet valves are raised from below by eccentrics) is only to be recommended, as the valves in the lifted position when the reversing gear is set central are clear of the linear lead and so remain without movement while running with regulator closed.

It only remains to determine what is the most reduced cut-off which is still admissible in ordinary working, when hauling light trains, from the economic point of view; *i. e.* starting from what point of cut-off would it be necessary to throttle the pressure in the steam chest so as to reduce the power? With this new system of utilizing the steam (parallel flow and large clearance spaces), it is possible to obtain accurate information on this point from the entropy diagrams above. Careful observations carried out in practice, which already have been begun, can alone lead to correct results.

The way indicated for the improvement of the steam locomotive is, to utilize the limited steam-producing power of the locomotive as much as possible, so as to obtain an increased economy in the working as well as increased power combined with as much saving in the weight of the locomotives as possible. The introduction of the parallel-flow principle on the locomotive, by the use of the Stumpf valve gear, is another step forward in this direction, which promises to make the advantages of superheated steam still more apparent, while the design is as simple as possible.

c) *Feed-water heaters. Feeding devices.*

1, 2, 3. — Apart from the comparatively-slight warming which the feed-water receives from the steam in the injectors, there is no special provision for heating the feed-water. The Rhetian Railway alone, in the case of some loco-

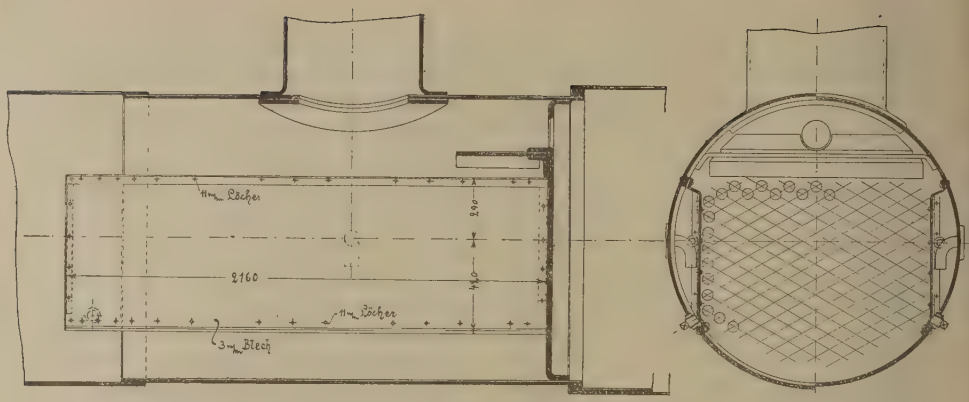


Fig. 77. — Chamber for warming on the locomotives of the Rhetian Railway.

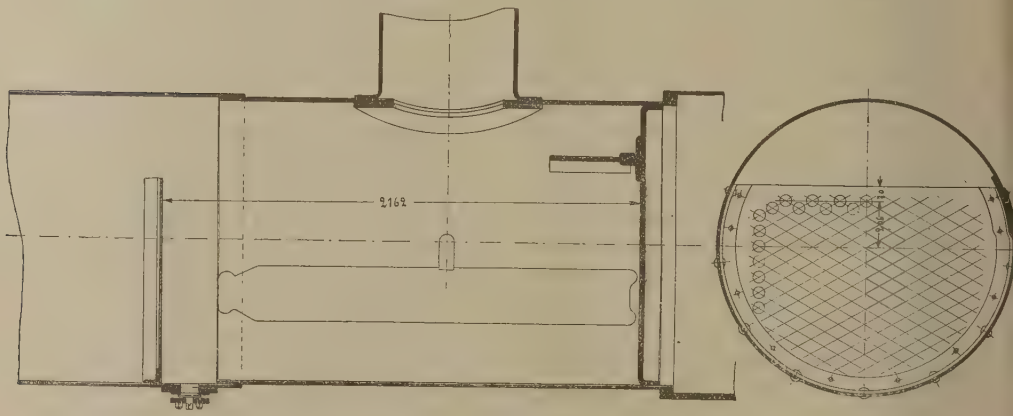


Fig. 78.

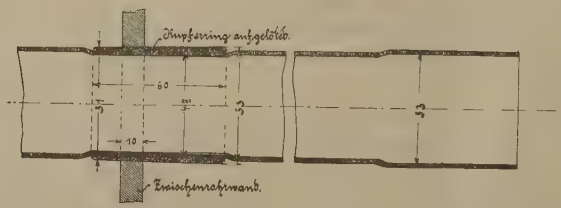


Fig. 79. — Intermediate tube-plate on the locomotives of the Rhetian Railway.

Explanation of German terms : Löcher = Holes 11 millimetres (7/16 inch), in diameter. — Blech = Sheet 3 millimetres (1/8 inch) thick. Kupferring aufgelötet = Copper ring brazed on. — Zwischenrohrwand = Intermediate tube-plate.

motives, introduce the feed-water into receptacles in the barrel, which are along the walls of the barrel, and about 2 metres (6 ft. 6 $^3/_4$ in.) long and 650 millimetres (2 ft. 1 $^5/_8$ in.) high. The feed-water enters these receptacles, and becomes heated there before it enters the barrel; holes 11 millimetres ($^7/_{16}$ inch) in diameter are provided near the circumference of the receptacle for the purpose (see fig. 77). On some of the locomotives of this railway an iron intermediate tube-plate, 10 millimetres ($^{13}/_{32}$ inch) thick, is put in at a distance of 2,150 millimetres (7 ft. $^5/_8$ in.) from the front tube-plate; it extends to about 45 millimetres (1 $^{25}/_{32}$ inches) above the top row of tubes, and joints between the tubes and the plate are made by copper rings which are brazed on and have a slight taper. The object aimed at is that the colder feed-water, entering the front part of the boiler, should there first receive a preliminary heating before it reaches the fire-box tube-plate (see figs. 78 and 79). These two systems aim at obtaining a better tightness of the tubes and at having the scale deposited chiefly in the front part of the boiler. No information is given as regards results obtained, especially as regards any excessive deposit of scale in the front part of the boiler.

Injectors of the ordinary patterns are everywhere used for the feed-water supply.

A feed-water heater lately introduced by the Hanover Maschinenbau Aktiengesellschaft, formerly G. Egestorff, of Hanover, is shown in figure 80. It is intended to utilize the heat which is no longer high enough to generate steam, in the front part of long smoke tubes, and also to deposit and retain the scale in the front part of the boiler.

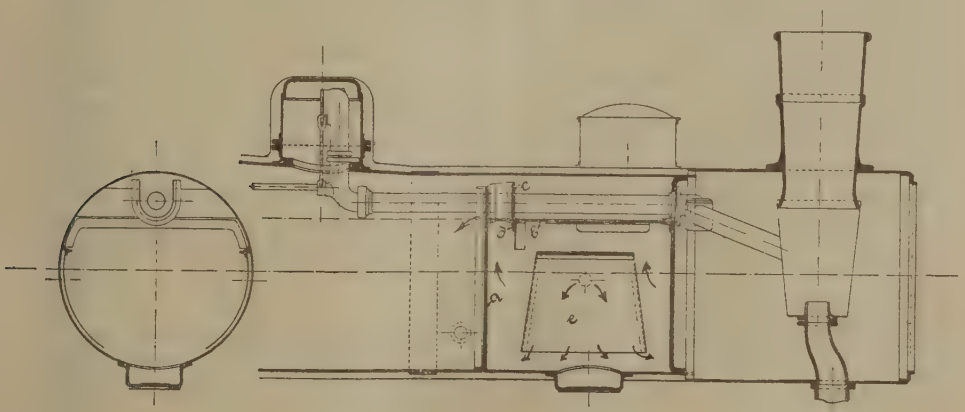


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Fig. 80. — Feed-water heater for locomotive boiler. — German patent No. 205, 542.

Vertical cross partition. — b and c = Partitions between steam space and feed-water space. — d = Projection of roof b to form air chamber. — e = Deflectors which send the water, to the bottom.

Final conclusions, subject VI-B.

(Germany, Denmark, Luxemburg, Holland, Norway, Sweden, Switzerland.)

a) Water-tube boilers are not in use. A few water-tube fire-boxes are in use, as a trial. There are no special systems of water-tubes in the fire-boxes.

b) Superheated steam is used more recently already on a larger scale; it is also intended to extend its use. It is to be recommended on account of the resulting economic advantages, for not only is there a saving of coal and of water, but the operation of the traffic is also facilitated by the greater power of the locomotives.

The W. Schmidt smoke-tube superheater, which is generally preferred, seems at present the most suitable system for producing superheated steam. The W. Schmidt smoke-box superheater will in the future be left out of consideration. The superheaters of the Pielock and Clench-Gölsdorf designs, which are more of the nature of steam driers, have at present only received limited applications; as they are cheap and easy to build and look after, they seem useful in cases in which one is content with steam having a temperature of 270 to 290° C. (518 to 554° Fahr.).

Superheated-steam locomotives are not to be recommended for light work, particularly if the locomotives have frequent stops at short intervals, or for shunting work.

Piston valves have given good results; flat slide valves are no more used. Valves of the Lentz design are at present in the experimental stage. Many administrations recommend the use of spring rings for piston valves.

With steam superheated to from 320 to 350° C. (608 to 664° Fahr.), the economic results prove satisfactory. The design of the new packings for the valve and piston rods can resist the deleterious influence of this high temperature just as successfully as the quality of the lubricating oil now obtainable for superheated steam.

Superheated-steam compound locomotives with four cylinders are now frequently used, and progress in this direction seems to promise good results.

Careful and accurate trials, extending over longer periods of time, in order to compare the performance of superheated-steam and wet-steam locomotives as regards the actual increase of power and the coal and water economy really effected in regular service, should, as the results so far obtained vary considerably, be carried out by the different administrations on a large scale as soon as possible, in order to determine the value of superheated steam more accurately. Particular attention should also be paid to the counterbalancing of the greater initial cost and the possible but as yet very uncertain increase in the cost of maintenance and repairs.

c) Devices for heating the feed-water to higher temperatures are not considered necessary, except by the Rhetian Railway. Injectors are generally used as being most suitable for feeding the boiler.

C. — Damage to boilers.

Deformations, grooving, pitting, and corrosion. Means employed to prevent this damage. Purification of the water and disincrustants.

1. *Processes for softening and purifying the water.* — It is the general opinion that proper and careful purification of the water *before* it is used is the best means for preventing the formation of scale, which has a bad influence on the working, increases the cost of maintenance and produces damage which shortens the life of the boilers.

At many places, suitable water is available, so that maintenance and working are satisfactory; there are comparatively-few places where bad water must be used, either because better water is absolutely not to be obtained, or could only be brought from elsewhere at an excessive cost. The processes for purifying water form a useful means for improving such waters.

Among the salts dissolved in water the most important as regards the formation of scale are calcium sulphate ($Ca\ SO_4$), and acid calcium carbonate ($Ca\ CO_3\ H_2\ CO_3$); silicates, calcium chloride, magnesium sulphate, magnesium chloride and acid magnesium carbonate are found in smaller quantities. In a few cases sodium chloride, (Na Cl), humic acid, and iron compounds turn up in injurious quantity.

As a rule, the administrations soften and purify the water by the addition of quick lime, sodium hydroxyde and sodium carbonate in the well-known apparatus. These apparatus differ chiefly in the manner in which the chemicals are added to the water which is to be purified; the lime and soda may be added separately or both together; the process may be automatic or not. Very much the same reactions take place with the magnesium salts as with the calcium salts, but not as completely; chlorides and sulphates are both acted on.

The reactions which take place in the case of acid calcium carbonate and calcium sulphate are as follows :

$$1^{\circ}.\quad Ca\ CO_3\ H_2\ CO_3 + Ca\ O = 2\ Ca\ CO_3 + H_2\ O;$$

Acid calcium carbonate + lime = neutral calcium carbonate + water.

Neutral calcium carbonate is nearly insoluble in water and separates out. In order to remove 1 part of calcium carbonate, which is dissolved by the carbonic acid in the water in the form of acid calcium carbonate, 0·56 part of quick lime is required.

$$2^{\circ}.\quad Ca\ CO_3\ H_2\ CO_3 + 2\ Na\ OH = Ca\ CO_3 + Na_2\ CO_3 + 2\ H_2\ O;$$

Acid calcium carbonate + sodium hydroxide = calcium carbonate + water.

In this case sodium hydroxyde, instead of lime, is used to remove carbonic acid from the acid calcium carbonate and to convert it into insoluble neutral calcium

carbonate. 1 part of calcium carbonate dissolved as acid salt requires 0·8 part of caustic soda. Sodium carbonate is formed in this reaction, which in its turn reacts with calcium sulphate; consequently the calculated amount of sodium carbonate, which has to be added must be reduced by 1·3 parts for each part of sodium hydrate used.

$$3^{o}.\quad Ca\,SO_4 + Na_2\,CO_3 = Ca\,CO_3 + Na_2\,SO_4;$$

Calcium sulphate + sodium carbonate = calcium carbonate + sodium sulphate.

The neutral calcium carbonate precipitates as it is insoluble, while the sodium sulphate remains in solution. To decompose 1 part of calcium sulphate 0·78 part of sodium carbonate is required.

As an instance of the reactions which can be effected in such processes and the improvement in the water, we give the results of the analysis of the water which is purified at Potsdam station, in Berlin.

The water contained in parts per million :

Impurities.	Original water.	After addition of 170 parts of sodium hydroxide and 122 parts of quick lime.
Calcium sulphate ($Ca\,SO_4$)	171	21
— carbonate ($Ca\,CO_3$)	208	2
Magnesium carbonate ($Mg\,CO_3$)	42	32
Silica ($Si\,O_2$)	19	18
Sodium chloride (Na Cl)	44	46
— sulphate ($Na_2\,SO_4$)	...	156
Total solid residue	516	310
Scale-forming impurities	440	73

Water which contains free sodium carbonate gives much trouble by violent priming and foaming. If the composition of the original water is apt to vary, it is advisable, in order to make sure that no sodium carbonate is present in the purified water, not to use the amount of softener theoretically deduced from the analysis, but only 80 per cent of it, a fraction which may be cautiously increased, in cases, to 90 per cent.

Instead of sodium carbonate, barium carbonate is also used in some installations.

Barium chloride is also used to a small extent in such processes. This reacts with the calcium sulphate ($Ca\,SO_4$), and barium sulphate precipitates, leaving calcium chloride in solution. If any magnesium carbonate is present, the reaction produces insoluble barium carbonate which precipitates, and magnesium chloride remains in solution.

If the scale-forming impurities are present in small quantities, say less than 100 parts per million, then as a rule no purification is attempted; if there are 150 to 300 parts, the plan sometimes adopted is to add the softener indicated by analysis, usually sodium carbonate, to the water reservoir or the tender tanks; if a considerable quantity of scale-forming compounds is present, the chemical treatment is generally carried out in special installations, whose action chiefly depends on the long and intimate intermingling of the water with the chemicals added. The insoluble precipitates are removed by settling and by filtration through wood wool or sand beds. The chemical reaction is assisted by the waste heat of steam engines, steam pumps, etc.

The softening of the feed water is adjusted so that about 6 to 8 (German) degrees of hardness are left, as water which is too soft gives trouble by bumping. In districts which take their water from deep-lying strata of chalk, the water which has a hardness of 30 degrees or more must be softened so that only 6 to 8 degrees are left. The German degree of hardness corresponds to one part of calcium oxide (Ca 0), or its equivalent, in 100,000 parts by weight of water. One part of magnesium oxide is equivalent to 1·4 parts of calcium oxide. One German degree of hardness is equal to 1·25 English or to 1·79 French degrees of hardness. One French degree of hardness corresponds to one part of calcium carbonate in 100,000 parts of water; one English degree to one part of calcium carbonate in 70,000 parts of water.

The water obtained from peaty soil or from damp wells often contains much iron; if this is to be used for boilers, the iron is generally removed by an aeration process; before the water enters the station tanks it is either led through special aeration appliances and filter beds, or is allowed to fall, much subdivided, from a height of 1·5 to 2·0 metres (4 ft. 11 in. to 6 ft. 6 $^3/_4$ in.). The soluble ferrous oxide it contains is oxidized by the intimate contact with the air and forms insoluble flocculent ferric oxide, which is either retained in the apparatus or in the more primitive processes becomes deposited at at the bottom of the tank on the sand in the form of mud, which has to be removed from time to time, or is kept from the delivery pipe by a vertical filter. When compressed-air pumps are used for delivering the water (*mammoth pumps*) the aeration is already effected during the lifting of the water, and the ferric oxide is retained by sand filters before the water enters the pumps. It is true that the iron content hurts the boilers but little, but if too much ferric oxide mud is formed, it can lead to irregular deposits of scale; moreover the water pipes tend to become blocked by the growth of *algæ* and *fungi* (*Leptothrix ochracæ* and *Crenothrix polyspora*) to which it serves as a culture-fluid.

In a few cases, the water contains an excessive quantity of common salt, which makes the water bump and foam; crystals of salt become formed at all the cocks and openings, and corrosion results. This for instance happened every year during a few months, at all the stations north of Magdeburg, which were near the Elbe, when that stream was high, as it then brought salt down from the saline districts. All remedies tried proved fail-

ures, and it was necessary to look out for new water-supplies and to give up the use of the contaminated water.

If hydrochloric, sulphuric, nitric or any other free acid is present in the water, either special chemical treatment is adopted or else the water is mixed with other good water in such proportion that the acid content is reduced to the admissible amount; this measure has sometimes to be adopted temporarily or even permanently, if for instance, water-courses from which supplies are obtained become contaminated by waste from manufactories, or water draining from strongly-manured fields, or acid water from coal beds or other strata obtains access to them. It not unfrequently happens that supplies which have become affected in this way have to be entirely given up, as chemical processes are not always able to protect the boiler against serious damage.

Organic impurities, such as finely-divided fibres of peat, and mineral matter in a state of suspension may turn up, during times of floods or heavy rains, in water which is generally good, and may contribute to the formation of scale. Administrations who may suffer from such conditions, try to keep such bodies out as much as possible by special filtering appliances, sand beds or filter presses, before the water enters the suction tubes of the pumps.

The Alsace-Lorraine Railway has a small Reisert-Derveaux water-purifier in use at Diedenhofen; it has an output of 10 cubic metres (353 cubic feet) of water per hour, and the water is satisfactorily softened to about 8 German degrees by the addition of milk of lime and baryta.

The Baden State Railway have three Reisert-Derveaux water-purifiers in use, and use the following quantities of quicklime and of sodium carbonate :

STATION.	The water contains, in parts per million.			Hardness, in German degrees.	Additions, per 100 cubic metres of water, in kilograms.	
	Calcium carbonate.	Calcium sulphate.	Total residues on evaporation.		Quicklime (96 per cent).	Sodium carbonate (98 per cent).
Heidelberg	132	175	428	14·6	13	2
Osterburken	243	160	438	20·2	30	6
Lauda	314		486	18·5	25	6

In Bavaria similar processes were adopted, the Voran, Reisert-Derveaux and Humboldt apparatus being used. In Saxony there are only two stations with water-purifiers; the Stingl-Bérenger system is adopted, and sodium hydroxide and sodium carbonate are added.

The Wurtemberg State Railway has Reisert-Derveaux water-purifiers; the chemicals used are either quicklime and sodium carbonate or quicklime and baryta.

The Danish Railway uses Reisert-Derveaux water purifiers (quicklime and so-

dium carbonate) in the case of larger installations, and Bruun-Kryger apparatus in that of smaller installations.

The Dutch State Railway has three installations with Humboldt water-purifiers, quicklime and sodium carbonate being added. Two of them have an output of 50 cubic metres (1,766 cubic feet) per hour, the third one of 100 cubic metres (3,532 cubic feet) per hour.

The Dutch Railway Company has a Humboldt water-purifier, acetylene-lime and sodium carbonate being added. The Luxemburg Prinz-Heinrich Railway has a Kennicot apparatus; quicklime and sodium carbonate are added.

The Swedish State Railway uses the Brun-Löwener apparatus.

The Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway, have no special water-softening plant. They add more or less sodium carbonate to the water in the reservoirs or in the tender tanks, according to the amount of impurities it contains. The St. Gothard Railway proceeds in the following way : Each time the boiler has been washed out by water under pressure (this must be done whenever the locomotive has run 3,000 kilometres [1,865 miles]), and has again been filled with water, 9 to 15 litres (1·98 to 3·3 gallons) (according to size of boiler) of a solution containing 10 per cent of sodium carbonate (Solvay soda) are added as the amount required for this first filling of the boiler. As regards the feed water subsequently required, 0·7 litre of this solution is added to each cubic metre of water in the tender. The latter addition is made each time the tender tanks are filled up, if the water contains lime; the operation is supervised by the inspectors at the locomotive sheds.

The Prussian-Hessian State Railway has water-purifiers of different kinds in use at a considerable number of stations; the additions made are quicklime and sodium carbonate or sodium hydroxide and sodium carbonate (see the instance of the Potsdam station at Berlin, mentioned above).

The Oldenburg State Railway, the Norwegian State Railway and the Stockholm-Rimbö Railway state that they do not take any measures for softening the water.

In order to determine what chemicals have to be added to the original water at a water-purifying plant, it must be carefully analysed in order to determine the amount of carbonic acid and of scale-forming impurities present. The operation must be controlled from time to time by the analysis of the purified water, and the proportion of the additions modified accordingly, so as to obtain the best possible result. Simple chemical tests, for which special instructions are issued, enable the staff on duty to see that the apparatus continues to work properly. The general supervision of the installation is entrusted to the officials on the spot, who have to see, if possible every day, that the apparatus is working properly. Some of the administrations have their installations examined and reported on every quarter by an expert from the firm who supplied the installation.

2. *Results obtained by the processes of water purification.* — All the administrations state that the results obtained are favourable, and that the use of the softened water is very satisfactory from the

*

economic point of view. Formerly, it frequently happened that tubes began to leak, in consequence of the formation of much scale; this seldom happens now, as the thickness of the layer of scale has been reduced from 6 to 8 millimetres ($^1/_4$ to $^5/_{16}$ inch) to only 1 or 2 millimetres ($^3/_{64}$ or $^5/_{64}$ inch), and the layers formed are soft and washed away when the boiler is washed out. The Wurtemberg State Railway mentions as a defect of the process, that locomotives which are fed with purified water, particularly those which often serve as reserve, show corrosion at the flue tubes and at the smoke tubes, at the joints where the copper sleeves are brazed on.

As there is less scale, the heat is utilized better, but no administration can give any figures as to the resulting economy in fuel.

The boilers require cleaning less frequently, the smoke tubes remain tight and in good condition for a longer time, the fire-box tube-plates are less strained by the re-expanding of the tubes. No figures are given as to the saving effected.

There is no doubt that the cost of maintenance is reduced and that the life of the boiler is lengthened by the use of softened water, as the boiler plates and their stays are attacked less, but no administrations can give any figures as to these resultant advantages.

The cost of purifying and softening the water varies a good deal. While the Prussian-Hessian State Railway gives 0·03 mark per cubic metre (1·309*d.* per 1,000 English gallons), the Alsace-Lorraine Railway gives 0·17 mark per cubic metre (9·269*d.* per 1,000 English gallons); but this high price is due to the small size of the installation. The original cost of the water is on the average about 0·10 mark per cubic metre (5·452*d.* per 1,000 English gallons) on the Prussian-Hessian State Railway; the purification adds accordingly about 30 per cent to the cost of the water.

It may be accepted that in the case of large installations with the work properly organized and properly controlled, the cost can be kept within 0·03 to 0·04 mark per cubic metre (1·309*d.* to 2·181*d.* per 1,000 English gallons).

It may be remarked that the Diedenhofen installation of the Alsace-Lorraine Railway is now no longer in use, although it softened the water concerned quite satisfactorily and removed all the scale-forming impurities. For serious corrosion was observed after a short time at the smoke tubes and tube-plates, which were traced, by the chemist who investigated the matter, to the presence of chlorides, especially of calcium and of magnesium, in the original water. This water was taken from the Moselle, which in consequence of waste products from chemical works contained these impurities in injurious quantity. When the water was used in its original state, the corrosion was not so great as the scale formed in this case a protective layer which reduced the injurious action of the chlorides. Taking these objectionable phenomena into consideration, it was necessary to give up trials of purified Moselle water, and the feed water is now obtained in part from the town water supply, which is mixed with unpurified Moselle water.

3. *Softening waters the hardness of which is mainly or largely due to calcium or magnesium sulphates, chlorides or nitrates.*

— This is effected in the apparatus described under heading 1. The introduction of zinc, to prevent the bad action of chlorides, was unsuccessful. Water containing a larger quantity of chlorides or nitrates is not used as feed water, or is at least avoided as much as possible. In order to prevent violent foaming, the water is not completely softened, but retains a hardness of 6 to 8°. The Baden State Railway at first softened it to 4 German degrees of hardness; but trouble arose, because more water was carried over than the injectors could replace. Should it happen that the water foams over, this is remedied by suitably reducing the amount of sodium carbonate added.

4. *The use of barium hydroxide, barium carbonate or barium aluminate.* — As already stated, barium carbonate is used at a few places, but only exceptionally, as it has been found as a rule that the addition of sodium carbonate and of quickline or of sodium hydroxide purifies hard feed water sufficiently. The Wurtemberg State Railway uses it in the Reisert apparatus in order to soften water having 24 German degrees of hardness; 200 grams (0·4409 lb.) of 80 per cent lime and about 400 grams of barium carbonate are added to each cubic metre (respectively 2 and 4 lb. per 1,000 English gallons) of water, and the hardness is reduced on the average to 6·8 German degrees of hardness. The amount of barium carbonate for reacting on the calcium sulphate is checked every day by tests, and the cost of the operation is 0·18 mark per cubic metre (9·814*d.* per 1,000 English gallons). The administration states that this method of purification works well, and that there has been no excessive priming.

On the Luxemburg Prinz-Heinrich Railway, barium aluminate has been tried, a definite quantity being put into the boiler every day, but the results obtained were not satisfactory.

5. *Attempts to determine the quantity of sodium salts when there is priming.* — Such attempts have not been made. The Prussian-Hessian State Railway, when treating water having a hardness of 21 German degrees, at first used 220 grams of calcined soda per cubic metre (2·20 lb. per 1,000 English gallons) of water; this was reduced to 135 grams per cubic metre (1·35 lb. per 1,000 English gallons), because there was violent priming and foaming. The Danish State Railway draws attention to the fact that the sodium sulphate content seems to be of as much importance from this point of view as the sodium carbonate content.

6. *Disincrustants placed directly in the boiler.* — Such have been tried by various administrations; in the case of water containing calcium sulphate, sodium carbonate has been placed directly into the tender, and according to the statements of the Baden State Railway, the Dutch State Railway and the St. Gothard Railway, good results have been obtained in this way. The Wurtemberg State Railway is at present making experiments in this direction. The Bavarian State Railway formerly placed a solution of soda in the boiler, but no longer does so now. On the Prussian-Hessian Railway, before the water-purifiers were installed, it was also usual to add soda to the water in the ten-

der, but this method has now become unnecessary. It is however still applied with success in the case of stationary boilers, which have to use water containing many scale-forming impurities; when the boiler has been washed, 0·25 to 0·50 kilogram (0·551 to 1·102 lb.) of soda is added in solution; the scale formed is less hard and is easy to remove. This keeps tubes from becoming leaky, but care has to be taken as regards the quantity of soda added.

The Prussian-Hessian State Railway and the Saxon State Railway are at present using, at a few of the locomotive depots, petroleum as an addition to feed-water. In the former case, the petroleum is generally introduced after the boiler has been washed out, 0·5 to 1·5 kilograms (1·102 to 3·306 lb.) of petroleum being added. The latter uses petroleum injectors and adds the petroleum drop by drop to the feed-water.

The petroleum is absorbed by the scale and the petroleum vapour subsequently evolved forces the scale off the boiler walls. The scale no longer deposits as hard scale, but as a granular, partly muddy mass which is easily removed. The trials made have shown that this method has given good results in all cases where it was not a question of feed water depositing very hard impermeable scale.

7. *Tendency of boilers to leak when softened water is used.* — This has not been observed by any of the administrations, unless the alkalinity of the water was increased by an excessive addition of soda. On the contrary, the tendency to leak at the tubes, stays or boiler seams is much reduced if the water is not made too soft, that is if it still has a hardness of about 6 German degrees.

8. *Defects in the interior of the boiler.* — 1° Cracks; 2° Pitting; 3° Grooving; 4° General surface corrosion.

The administrations give the following information about these defects :

Alsace-Lorraine Railway. — Cracks occur in the top bend of the fire-box tube-plate. Pitting and grooving are found principally in the lower part of the barrel.

Baden State Railway. — Cracks occur more especially in the copper tube-plate, at the sides and at the crown of the fire-boxes, between the stays. Pitting was found on the bottom of the barrel, extending over a width of about 0·5 metre (1 ft. 7 $^{11}/_{16}$ in.), in the case of locomotives which had to use much scale-forming water. Grooving occurs at the bottom of the barrel, at the seam between the middle and the front ring, and in the fire-box walls along the foundation ring, where the scale cannot be properly removed by washing.

Bavarian State Railway. — Cracks occur at the wash-out holes, if not strengthened, and at the outer rows of stays. Pitting is found in the lower half of the barrel, particularly above the boiler supports. Grooving is found in the bends of the front and back wall of the fire-box, in the fire-box walls above the foundation ring, and at the cross seams of the boiler. General corrosion occurs in the lower half of the boiler.

Oldenburg State Railway. — Cracks in the interspaces and bends of the copper

tube-plate. Pitting in the lower part of the barrel. Grooving at the inner sides of the fire-box shell above the foundation ring, at the seams of the barrel, in the bends of the back wall of the fire-box shell. General corrosion at the sides of the fire-box shell and in the corners; also outside at the bottom of the cross seams of the barrel.

Saxon State Railway. — Small cracks and corrosions, produced by the oxygen of the air carried in, at the points where the feed-water is admitted. Cracks at the bends of the front wall of the fire-box shell, the result of fine cracks produced during the bending. Otherwise nothing.

Wurtemburg State Railway. — Cracks at the stays, in the interspaces of the fire-box tube-plates, in the top bend of the fire-box tube-plate, between the vertical stay-bolts of the fire-box walls, starting from the stay-bolts at places where individual interspaces have bulged out in consequence of the deposit of much scale, at the gusset stays, at the top corners and cross ties of the roof of the fire-box shell, at the lower corners of the fire-box, at the stay-bolt holes of the extreme vertical rows at the back of the fire-box and of the top horizontal rows of the side walls of the fire-box, and at the stiffening ribs of the smoke-box tube-plate.

Pitting in the lower part of the barrel rings, particularly at the caulked seams and in the middle and back ring, as well as at the smoke tubes.

Grooving in the lower part of the fire-box walls along the upper edge of the foundation ring, at both sides of the bends of the walls of the fire box shell, between the stay-bolts of the extreme vertical rows of the back of the fire box and of the top the horizontal rows of the sides of the fire-box; at such parts of the fire-box where any stiffeners begin; at the bottom part of the bend of the smoke-box tube-plate. Except as regards the rust grooves in the foundation ring, the rust lines generally cover deeper grooves, more of the nature of cracks.

Prussian-Hessian State Railway. — Cracks in the barrel at the caulking line of the longitudinal seam, in the case of wrought-iron plates; in the fire-box tube-plate at the bends and in the interspaces; in the smoke-box tube-plate at the bends; in the back plates of the fire-box at the fire-hole and at the bends; in the throat plate at the upper part of the bends; in the back plate of the fire-box shell, between the wash-out holes; at the back gusset of the back of the fire-box.

Pitting along the whole length of the bottom of the barrel, particularly immediately in front of the edges of the seams. Grooving in the lower part of the cross seams of the barrel; in the bends of the throat plate and the back of the barrel; immediately above the foundation ring along its whole length, and most at the throat plate. General surface corrosion at the lower part of the front rings of the barrel, particularly below the smoke-box opening and on both sides of it, at the throat plate in the bends and at the back of the fire-box in the bends and above the foundation ring; at the inside stay heads and at the roof stays at water level.

Danish State Railway. — Cracks most frequently occur in the bends of the smoke-box tube-plate; pitting most frequently in the bottom of the barrel and in

the front ring of the barrel near the smoke-box. 3° and 4° not at special points.

Dutch State Railway. — Cracks do not occur; pitting is generally found in the bottom half of the barrel, in the front tube-plate and in the side and front plates above the fire-box foundation ring.

Dutch Railway Company. — Corrosion is chiefly found in the inside of the barrel and in the fire-box shell at the foundation ring.

Luxemburg Prinz-Heinrich Railway. — Cracks in the tube-plates, at the wash-out holes, in the flanged plates of the fire-box shell and at the fire-hole. Pitting in the bottom of the barrel, in the foundation ring, in the plates of the fire-box shell. Grooves at the height of the usual water level, in the smoke-box tube-plate, in the back fire-box plate. Surface corrosion in the bottom part of the barrel rings.

Swedish State Railway. — Cracks in the copper tube-plate and in the inter-spaces, where the plate is worn away by the solid particles carried over by the hot gases, and in the inner side (more rarely in the outer side) at the bends. Also from the rivet holes to the edge of the plate, at the bulges between stay-bolts, at the lower parts of the front of the fire-box shell.

Corrosion in the side plates of the fire-box around the rivet heads, in the back plate at the fire-hole, in the plates of the fire-box shell and inside at the bottom of the barrel.

Stockholm-Rimbö Railway. — Cracks at the stays, grooves in the foundation ring, corrosion in the corners of the fire-box and in the smoke-box tube-plate.

Swiss Federal Railway. — Cracks in the bends of the plates of the fire-box shell and of the tube-plates, in the plate stays and in the fire-box crowns. Pitting is found in particular in fire-box shell plates made of ingot iron. Grooves occasionally in the throat plates, but particularly in the fire-box shell along the foundation ring. General surface corrosion is rare.

St. Gothard Railway. — Cracks especially at the top corners of the copper tube-plates if bent to too small a radius. The defects 2°, 3° and 4° were observed especially in the bottom parts of the barrel of the boilers, when examined after having been in use for eight years, and had as yet but little depth and extension. After about fourteen years individual instances had become so deep or so extended that it was necessary to renew some or all the rings of the barrel.

Rhetian Railway. — Cracks in the back and front plate of the fire-box. Pitting in the lower part of the boiler and in the lower parts of the fire-box shell.

Norwegian State Railway. — Cracks in the plates at the fire-hole and in the vertical bends of the fire-box shell. In the copper fire-boxes they generally run vertically in the bends.

9. *Statistics of the defects.* — Only a few administrations make sketches, when the boilers undergo heavy repairs, of the defects referred to in question 8, showing the position, extent and depth of those defects; for instance the Alsace-Lorraine Railway, the Baden State Railway, the

Bavarian State Railway, the Wurtemberg State Railway and the Oldenburg State Railway do so. Most of the administrations limit themselves to making notes on the subject in the boiler books or on the repair sheets, and only in exceptional cases of special importance are sketches made or plaster of Paris or lead casts taken.

The Saxon State Railway and the Danish State Railway state that they confine themselves to making notes.

Some of these sketches, as annexed to the boiler books, are reproduced in figures 81 to 87. The figures inscribed represent the depth of the corrosion and of the pitting. The boiler plates are shown as unrolled in figures 81 to 85.

10. *Prevention of defects when designing the boilers. Breadth of the water-spaces in the fire-box and delivery of the feed-water.* — If the defects are not due to improper treatment or to bad quality of the feed-water, but to the nature of the material, heat expansion, vibrations, special stresses, etc., attempts are made to counteract them by suitable selection and arrangement of stays and stiffeners, by giving the plates a suitable thickness, by allowing a sufficiently-large radius at the bends and corners, by increasing the size of the interspaces in the fire-box tube-plate and by carefully selecting and testing the material most suitable for the part concerned.

The Danish State Railway, in a supplementary note, draws attention to two improvements which have been carefully tested in practice during the last few years, with good results, and which are consequently strongly recommended for further use. A description of them is given below, reprinted from the original paper by Mr. O. Busse, manager of the Danish State Railway, Copenhagen.

On keeping fire-box foundation-rings tight.

We have often heard the opinion expressed, in connection with locomotives, that the foundation ring is the weak point of the locomotive boiler, not as regards strength, but as regards keeping it tight and as regards corrosion of the boiler resulting in consequence of absence of tightness. Such chiefly appears, on a more extended scale, at the corners; and no amount of caulking will thoroughly cure the evil. Now what has been done, in order to obtain greater tightness? Originally, there was a single row of rivets; this has been replaced by a double and even a treble row, and the foundation ring has been drawn down at the corners and made smaller, so that it only forms a connexion with the outer plate (1). This design is a good one, but making the foundation ring was an expensive operation as long as it was necessary to forge it; now that it is possibly to make the ring of a steel casting, this system is well worth attention. It is well known that putting in a double row of rivets does not give the results desired, and I observed some years ago, in the case of a number of boilers which were under my supervision, that the old single row of rivets could produce very good tightness. This induced me to investigate the question, and I subsequently used single riveting at the foundation rings of a large number of boilers, and I certainly had no reason to regret it.

My investigations were in two directions :

1° What produces the want of tightness?

2° Is single riveting strong enough?

(1) *Eisenbahntechnik der Gegenwart*, vol. I, second edition, p. 170, fig. 164.

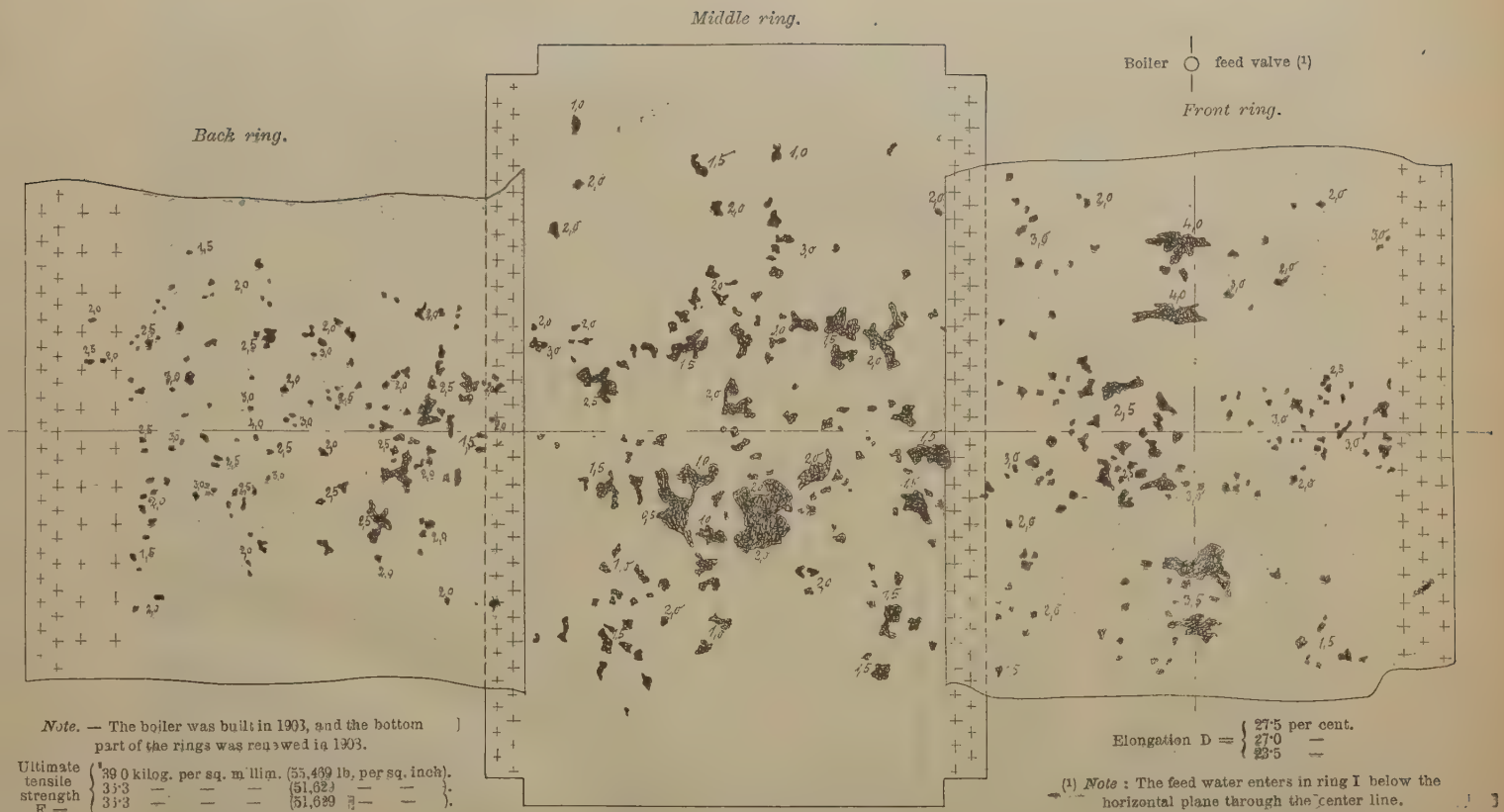
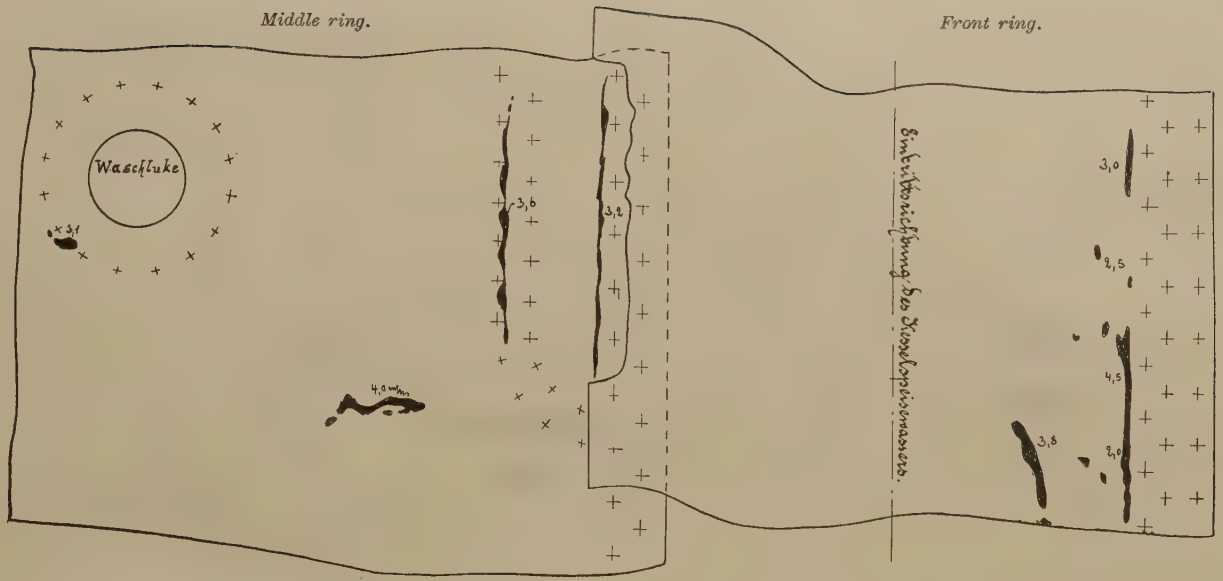

Middle ring.
Boiler
feed valve (1)
Front ring.
Back ring.
Note. — The boiler was built in 1903, and the bottom part of the rings was renewed in 1903.
Ultimate tensile strength F =
39·0 kilog. per sq. millim. (55,469 lb. per sq. inch).
35·3 — — — (51,629 — —).
35·3 — — — (51,629 — —).
Elongation D =
27·5 per cent.
27·0 —
23·5 —
(1) Note : The feed water enters in ring I below the horizontal plane through the center line.
Pitting and general surface corrosion.

Fig. 81. — Corrosion in barrel of locomotive 8001 of Prussian-Hessian State Railway.

Note. — The boiler was built in 1903. In 1908, the bottom of all the rings was renewed.

Metal: Ingot iron. Ultimate tensile strength, F = { 35·8 kilograms per sq. millimetre (50,918 lb. per sq. inch). / 36·1 — — — (51,344 — —). / 36·6 — — — (52,055 — —). Elongation, D = { 25 per cent. / 28 — — / 25 — —

Fig. 82. — Corrosion in barrel of locomotive 8002 of Prussian-Hessian State Railway.



Pitting, grooving.

Remarks :
The boiler was supplied in 1897.
In 1908, the bottom of the front and of the middle ring was renewed.

Metal : Ingot iron. Ultimate tensile strength, F = { 38·8 kilograms per sq. millimetre (55,184 lb. per sq. inch). / 36·2 — — — (51,487 — — —). } Elongation, D = { 25·1 per cent. / 28·3 — — }

Fig. 83. — Corrosion in barrel of locomotive 1809 of Prussian-Hessian State Railway.

Explanation of German terms : Waschluke = Wash-out hole. — Eintrittsrichtung des Kesselspeisewassers = Direction in which feed water enters.

Front ring.

Fig. 84. — Corrosion in barrel of locomotive No. 7252 of Prussian-Hessian State Railway.

Remarks :

The boiler was built in 1895. — In 1908, the bottom of the front ring was renewed.
Metal : ingot iron, ultimate tensile strength F = 35·4 kilograms per square millimetre (50,349 lb. per square inch).

Front ring.

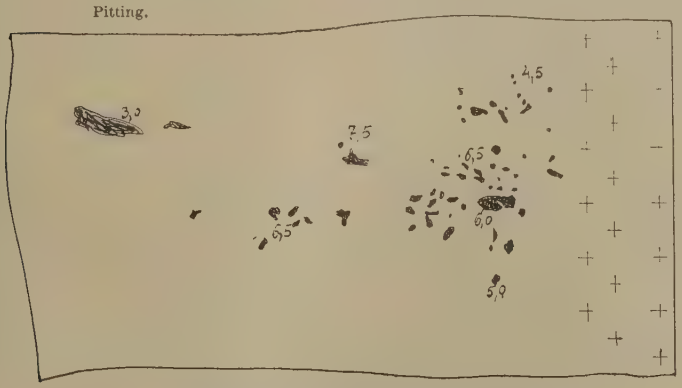
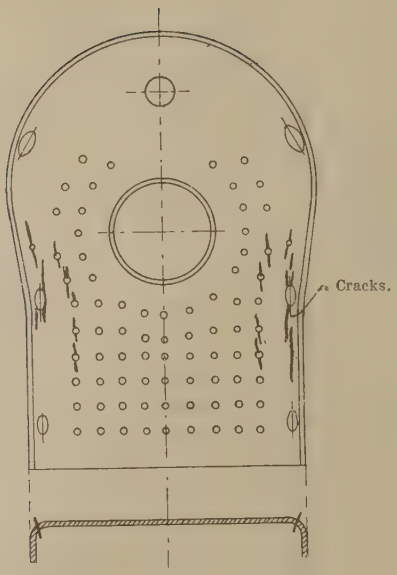


Fig. 85. — Corrosion in barrel of locomotive No. 7237 of Prussian-Hessian State Railway.

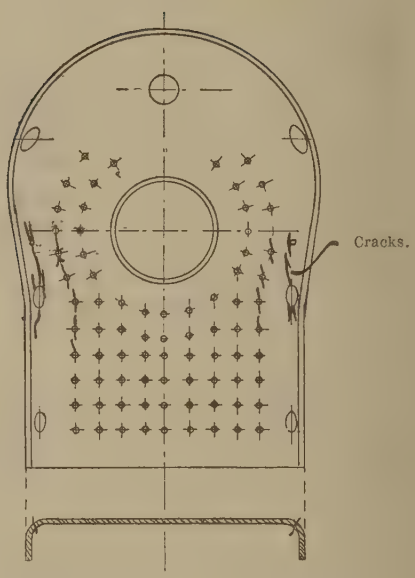
Remarks :

The boiler was built in 1899. — In 1907, the bottom of the front ring was renewed. — Metal : ingot iron, ultimate tensile strength F = 34·0 and 34·7 kilograms per square millimetre (48,357 and 49,343 lb. per square inch elongation D = 27·0 and 26·2 per cent



The boiler was supplied in 1895. — The fire-hole plate was replaced in 1909. — Metal : ingot iron, ultimate tensile strength, 39·9 kilograms per square millimetre (56,749 lb. per square inch); elongation, 26·8 per cent.

Fig. 86. — Fire-hole plate of locomotive 7254 of Prussian-Hessian State Railway.



The boiler was supplied in 1896. — The fire-hole plate was replaced in 1909. — Metal : ingot iron, ultimate tensile strength, 42·1 kilograms per square millimetre (59,878 lb. per square inch); elongation, 24·3 per cent.

Fig. 87. — Fire-hole plate of locomotive 7260 of Prussian-Hessian State Railway.

As each rivet is put in and headed, the boiler plate in the immediate neighbourhood becomes stretched; this stretching increases from rivet to rivet and makes itself most apparent at the weakest points. These are the corners, where some of the rivet heads are rather far apart and where screws must also be used because there is no room in the corner for rivets going through; it is true that this effect is weakened by riveting the corner first, then the middle and then putting in rivets alternately from the corner and from the middle, in order to distribute the stretching. The stretching is however not wholly avoided; it becomes the more extensive, the more rivets are used; in addition, double riveting makes a further division along the caulking edge necessary, so that the plate is not held so tightly against the foundation ring. Consequently the caulking can not penetrate so far, as with closer, single division; it is consequently more easily loosened by small particles of scale dropping in. But when the water has worked through to the caulking edge, leakage, rusting and corrosion take place, soon with destructive results.

Thus double riveting is merely a disadvantage as regards maintenance of tightness; it remains to be seen whether it is

necessary from the point of view of strength, or whether single riveting is not strong enough.

We will as an instance examine the case of a fire-box, intended for a working pressure of 15 kilograms per square centimetre (215·3 lb. per square inch), and having a foundation ring 100 millimetres (3 $^{15}/_{16}$ inches) wide, with rivets 26 millimetres (1 $^{1}/_{32}$ inches) in diameter, pitch 65 millimetres (2 $^{9}/_{16}$ inches). We have to consider the shearing stresses and the tensile stresses acting on the individual rivets, and the tensile stresses acting on the boiler plate. The shearing forces acting on each length amount to $10 \times 6{\cdot}5 \times 15 = 975$ kilograms; the cross-section of a rivet is 531 square millimetres; the shearing stress is accordingly

$$\frac{975}{2 \times 531} = 0{\cdot}918 \text{ kilog. per sq. millimetre.}$$

The boiler plate between the rivet holes is assumed to be 17 millimetres ($^{11}/_{16}$ inch) thick; it accordingly has a cross section of 17 (65-26) = 663 square millimetres. The tensile stress is

$$\frac{975}{2 \times 663} = 0{\cdot}735 \text{ kilog. per sq. millimetre,}$$

which is very low even for copper.

The tensile force acting on a rivet is equal to the pressure of the steam of the boiler plate, measured from the lower row of stay-bolts to the row of rivets. With a distance of 100 millimetres (3 $^{15}/_{16}$ inches), a width of 65 millimetres (2 $^{9}/_{16}$ inches) and a pressure of 15 kilograms per square centimetre (215·5 lb. per square inch) this also gives $10 \times 6{\cdot}5 \times 10 = 975$ kilograms; the tensile stress acting on the shaft of the rivet is accordingly

$$\frac{975}{531} = 1{\cdot}84 \text{ kilograms per square millimetre.}$$

When the tensile stress is 1·84 kilograms per square millimetre (2,617 lb. per square inch) and the shearing stress is 0·918 kilogram per square millimetre (1,306 lb. per square inch), the total stress resulting from compounding them only amounts to 2·44 kilograms per square millimetre (3,470 lb. per square inch).

These stresses accordingly do not make it necessary to have a double row of rivets, and as the latter is bad for tightness, as show above, its use should be given up.

Hence both experience and calculation enable me to recommend that fire-box foundation-rings should have single rows of rivets and drawn-down corners, which are connected with the outer boiler plate by about eight rivets.

It is generally recommended, and especially by the Baden State Railway, that there should be an ample supply of large and accessible openings for cleaning purposes, used for frequent and careful washing out of the boiler. Several railways recommend that the boiler should be properly supported, so that it can expand on the frame without strain, that movable roof stays should be used at the front and back of the fire-box roof and that all fittings inside the boiler should be designed with a view to obstructing the circulation of the water as little as possible, for instance by spacing the smoke tubes further apart. Apart from this it is the general opinion that the development of the present designs satisfies existing needs, and that the defects referred to in question 8 do not appear so largely as to make any material alterations in the design of boilers necessary.

The Wurtemberg State Railway, in order to avoid as far as possible any injurious strains in the fire-box tube-plate, which might result from the heat expansion of the large smoke tubes in

the superheated steam boilers, uses elastic smoke tubes with corrugated ends, made by the Mannesmann process. The many trials made of special metals for stays and stiffeners have a similar object in view.

The breadth of the water-space around the fire-box varies between 60 and 80 millimetres (2 $^{11}/_{32}$ and 3 $^{1}/_{8}$ inches) at the foundation ring, and usually amounts to 70 millimetres (2 $^{3}/_{4}$ inches); it increases upwards to 100 or 150 millimetres (3 $^{15}/_{16}$ or 6 inches); at the side of the throat plate in front of the tube-plate the increase is even comparatively larger.

Many of the administrations deliver the feed-water in the front third of the barrel, about halfway up, on both sides of the centre line of the boiler, by means of injectors, at a distance of from 500 to 1,600 millimetres (1 ft. 7 $^{11}/_{16}$ in. to 5 ft. 3 in.) from the smoke-box tube-plate.

The Baden State Railway, the Danish State Railway, the Norwegian State Railway and the Swedish State Railway place the point of delivery near the middle of the barrel.

The Wurtemberg State Railway sends the feed-water from the injectors through two long pipes going through the back wall of the fire-box and over the fire-box crown to the front part of the barrel, where the water is delivered a little above the top row of the smoke tubes at a distance of about 1 metre (3 ft. 3 $^{3}/_{8}$ in.) from the smoke-box tube-plate.

On several railways devices are to be found, as on the Wurtemberg Railway, for warming the feed-water while entering; for instance on the Swedish State Railway where the water is led through pipes to the front part of the barrel.

In order to prevent excessive deposit of scale, such as is observed in the smoke tubes near the spots where the feed-water enters, several administrations do not allow the water to flow straight into the boiler, but put in baffle plates to deflect it and distribute it more uniformly. On several boilers of the Prussian-Hessian State Railway, a definite improvement has been obtained in this way, as far as scale is concerned, but there was greater corrosion in the parts reached by the deflected water. The Bavarian State Railway has obtained good results with these baffle plates. Several administrations also use the appliance for preventing the formation of coherent scale, described by Mr. Karl Gölsdorf in the *Bulletin of the Railway Congress*, 1907, page 976.

Attention may also be drawn to figures 45, 48, 51 to 60, 63 to 66, 78 and 79; the latter show the arrangement adopted on the Rhetian Railway.

11. *Washing out the boilers.* — The best means for preventing damage to boilers which are well designed and properly treated is certainly timely and careful washing out; consequently all the administrations attach particular importance to the proper execution of this work.

Opinions differ as to whether hot or cold washing is preferable. The Alsace-Lorraine Railway, the Baden State Railway, the Bavarian State Railway, the Oldenburg State Railway, the Saxon State Railway, the Prussian-Hessian State Railway, the Dutch Railway Company, the Luxemburg Prinz-Heinrich Railway, and also the Stockholm-Rimbö Railway, pronounce in favour of hot washing out, which they as a rule apply. The Wur-

temberg State Railway, the Danish State Railway, the Dutch State Railway, the Norwegian State Railway, the Swedish State Railway, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway use cold water. The last four railways, as well as the Wurtemberg State Railway, go in for hot washing out at a few depots.

When hot water is used, the steam from reserve locomotives or from a stationary plant is utilized in the injectors of other locomotives or by means of the Körting or some other steam jet; the tender or other water becomes heated to a temperature of 50 to 60° C. (122 to 140° Fahr.) and is forced in the form of a jet through the openings provided for the purpose of washing out the boiler.

When reserve locomotives are used, the feed-water pipe outside the cab of all locomotives has a branch with a screwed union, which is closed by a screwed cap with a coned seat. If a locomotive is to be washed out, the cap is taken off the end and a hose joined on; the boiler valve is closed and the injector is started. The powerful jet of hot water forced out by the steam acting in the injector makes quick and effective washing out possible.

The Baden State Railway proceeds in the following way: the steam of the locomotive which is to be washed out, is blown off into the tender and the water in the tender is heated to about 60° C. (140° Fahr.). When all the steam has escaped, the cover of a boiler valve is removed, cold water is introduced through the opening and at the same time the blow-off cock is opened. In doing this, the water is kept at the same level. When the temperature of the water which is running away has fallen to about 60° C. (140° Fahr.), the supply of cold water is stopped, and the water in the boiler is run off quickly. Before all the water has run out, the hot tender water is injected by a portable electrically-operated centrifugal pump under a pressure of 4 to 5 atmospheres. At the same time, wire hooks are introduced through the openings, and any scale loosened as much as possible. The rest of the hot water is then used to fill the boiler again. At the newer locomotive depots, where there is much traffic, the waste steam of the locomotives stabled there is sent through a system of pipes to the tank of a water tower. The water so heated is then distributed through a second system of pipes to the locomotive sheds where it can be used for washing out boilers.

Similar arrangements like the last, with a tank fixed at a height, to which locomotive steam or steam from stationary boilers is led, are also used on other German and on Swedish lines.

The steamjet pumps are generally arranged at the end wall of the locomotive shed in such a way, that the water comes up from the supply below, while the steam supply comes from the back. The delivery orifice of the steam pump is joined to a system of iron pipes, laid below the floor and extending if possible through the whole shed. The pipes have an inside diameter of about 40 millimetres (1 $^{9}/_{16}$ inches) and branches are laid to the separate locomotive stands, for supplying the water for washing to the locomotives. In order to prevent any violent water hammer action in the piping, an air chamber of sufficient size is interposed near the pump orifice (old gas-

holders from passenger carriages or such like). The hot water is supplied at a pressure of 3 to 5 atmospheres.

The advantage of hot washing is that the excessive and injurious cooling of the boilers is avoided and that the locomotive, after it has been washed out, is again ready for work in the shortest possible time. The whole operation including refilling the boiler with hot water can be completed in four hours.

With cold washing, a period if possible of at least twelve hours is allowed for the boiler to cool. The pressure used is seldom more than 1·5 atmospheres, according to the height of the water tank; when the water is drawn from an existing town supply it has a pressure of up to 5 atmospheres.

On the Norwegian State Railway, the boiler is cooled by introducing water into the upper part of the boiler till it is quite full. Then the blow-off cock is opened, but only so much so, that the boiler remains full, cold water entering at the same rate. The cooling is continued for one and a half to two hours, according to the size of the boiler, until the boiler has cooled to about blood heat. Then the water is run out and the boiler emptied, and the washing out started; cold water under a pressure of 4 to 7 atmospheres is used. This saves time as compared with waiting for twelve hours.

The Swiss Federal Railway, which at many places has high-pressure water supplies available, uses cold water under a pressure of 10 to 16 atmospheres.

Formerly, it was generally adopted as a principle, that the locomotive crew had to wash out their locomotives themselves; on the one hand, this made it possible to make definite individuals responsible for keeping their boilers clean; on the other, the crew had the desire to keep the boilers in as good a steam-producing condition as possible, the coal premiums being taken into consideration. More recently, the cooling of locomotives, on the American plan, has become usual on many railways, and many administrations pay much attention to the full utilization of the crews; accordingly, the crews no longer have to wash out the locomotives, but this work is entrusted to special men at the sheds, who are trained for the purpose, and supervised by the officials, but only can be made responsible to a limited extent. If sufficient and careful supervision is exercised, it is still possible in this way to keep the boiler satisfactorily clean; but the supervision is sometimes defective, the men concerned have no longer the direct interest of the former washers, and the crew, which now receives the locomotive without knowing its condition inside, has to trust to luck; in many cases, it also no longer has the interest of the matter at heart, as the former premium conditions have been altered. Hence it happens that the boilers not unfrequently have but a short life, and that the defects referred to in question 8 begins to appear sooner than was formerly the case. As in this way the capital expended is used up prematurely and the working and maintenance expenses are materially increased by the reduced power and by the trouble, this should be a serious warning to treat the boilers as well as possible; and the Baden State Railway is perfectly in the right when it states : " Boiler defects are only to be

avoided by careful washing and by using purified water. "

The average distance run between two washings out varies very much, between 500 and 6,000 kilometres (between 310 and 3,728 miles). It depends in the first place on the working shifts of the locomotive crews, then also on the quality of the feed-water. The statements made by the different railways are as follows : Prussian-Hessian State Railway, 500 to 3,000 kilometres (310 to 1,864 miles), or time intervals of 10 to 12 or at most 14 days; Alsace-Lorraine Railway, passenger and express locomotives, 4,000 to 6,000 kilometres (2,485 to 3,728 miles); Baden State Railway, 1 to 4 weeks, according to quality of water; Bavarian State Railway, 8 to 12 days; the Oldenburg State Railway, goods locomotives 1,000 kilometres (621 miles), express locomotives 3,500 kilometres (2,175 miles); Wurtemberg State Railway, express locomotives 3,200 kilometres (1,988 miles), passenger locomotives 2,700 kilometres (1,678 miles), goods locomotives 1,560 kilometres (969 miles), on the average; Danish State Railway, about 700 kilometres (435 miles); Dutch State Railway, express locomotives, about 1,000 kilometres (620 miles); Dutch Railway Company, 1,000 to 1,500 kilometres (620 to 930 miles); Luxemburg Prinz-Heinrich Railway, about 2,000 kilometres (1,240 miles); Swedish State Railway, usually 1,200 kilometres (746 miles), but up to 6,000 kilometres (3,728 miles) if the feed water is very good; St. Gothard Railway, 3,000 kilometres (1,864 miles), or at least once a month; Rhetian Railway, about 1,600 kilometres (994 miles); Norwegian State Railway, about 3,500 kilometres (2,175 miles) in the case of express locomotives, about 2,500 kilometres (1,550 miles) in that of goods locomotives, or on the average every ten to twenty days.

12. *Blowing off the boiler under pressure. Blow-off cocks.* — If bad water, containing much scale-forming impurity, is in use, the boilers are blown off at short intervals, of three or more days, at a low pressure, till about one third of the water has escaped through the blow-off cock, which is nearly always placed in the front plate of the fire-box, at the bottom just above the foundation ring; exceptionally a blow-off cock is also placed in one side plate or in each side plate.

When good or properly-purified feed-water is used, this operation is unnecessary, but it is sometimes necessary when the water is softened by the addition of sodium carbonate in the tender, if the deposit is wholly in the form of mud. An excessive deposit of mud results in the fittings, the valve chests and the piston becoming very dirty and, with the assistance of the oil residues, in forming crusts at the edge of the exhaust.

The blowing-off under pressure is also effected through cocks placed at the side of the barrel, and this is done in the case of the Gölsdorf apparatus for preventing the formation of scale in boilers (1) which are of late being used on the Baden State Railway, the Swedish State Railway, the Wurtemberg State Railway and the Swiss Federal Railway. A preliminary comparative trial made with this appliance on

(1) See *Bulletin of the Railway Congress*, 1907, pp. 976 to 979.

*

the Baden State Railway showed that the average amount of mud washed out of boilers not fitted with this appliance was about 48 kilograms (105·8 lb.), while it amounted to about 37 kilograms (81·5 lb.) in the case of boilers fitted with it and doing the same work. The Swedish State Railway also reports favourably about these appliances and states that the time interval between two washings out can be doubled in consequence of their action.

The Saxon State Railway has quite recently replaced the blow-off cock by a valve at the front plate of the fire-box shell.

Blow-off cocks and valves are shown in figures 88 to 93.

13. *Strongly-corrosive water containing mineral acid.* — All the administrations state that such water should not be used. As regards the occurrence of such water, the following administrations give particulars :

The Alsace-Lorraine Railway analysed the Moselle water, referred to under questions 2 and 7, which was strongly corrosive after softening, and obtained very varying results, which did not make it possible to come to any definite conclusion as to the nature of the chlorine compounds present. Consequently the following method was adopted :

A piece of smoke tube which was strongly corroded was chucked in a lathe, and the corroded surface was turned off. The turnings were then extracted with water and the solution obtained was examined. The contents found, calculated as percentages of the weight of the turnings, were :

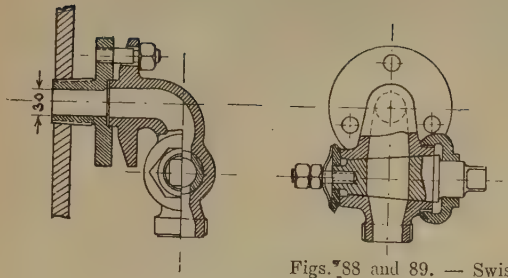
Calcium sulphate	0·008
— chloride	0·301
Ferric chloride	0·025
Magnesium chloride . . .	0·613
Sodium chloride	0·137

(See also under question 2.)

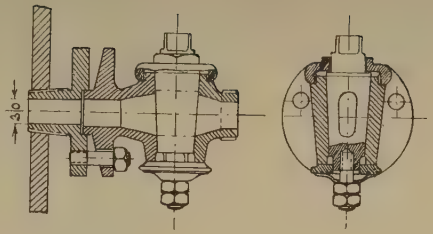
The water used on the Prussian-Hessian State Railway as feed-water at Altona Station, which is sent from the source at Langenfelde by the water-works there, is not suitable in its original state; for with locomotives fed with this water the smoke tubes and roof stays near the copper fire-box tube-plate (up to distances of 200 millimetres [7 $^{7}/_{8}$ inches]) become corroded rusted through after being in use a comparatively short time. New tubes had to be replaced after only four or five months, and it frequently happened that a tube burst in consequence of deep pitting.

According to chemical analysis, 100,000 parts of this water contain :

Total solid residues heated to 180° C. (356° Fahr.)	19·00	parts.
Loss on ignition	4·00	—
Mineral constituents.	15·00	—
The latter contained :		
Calcium sulphate.	7·46	—
Sodium chloride	3·51	—
Other substances, chiefly carbonates	4·03	—



Figs. 88 and 89. — Swiss Federal Railway.



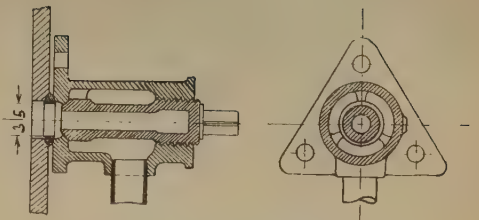


Fig. 90. — Alsace-Lorraine Railway.

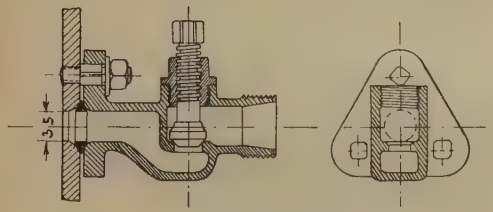


Fig. 91. — Saxon State Railway.

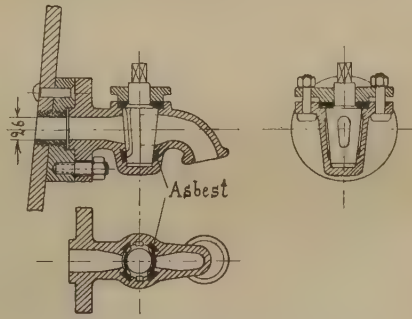


Fig. 92. — Danish State Railway.

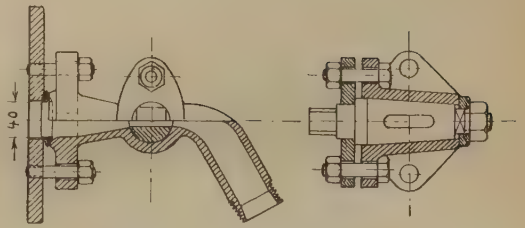


Fig. 93. — Prussian State Railway.

Figs. 88 to 93. — Blow-off cocks and blow-off valves.

Explanation of the German term: Asbest = Asbestos.

Although this would tend to show that this water is a suitable feed-water, yet experiments and daily observations have shown that it is not suitable at all. The water which appears to be saturated with gases (carbonic acid and air), contains per litre 14·99 cubic centimetres (4·16 cubic inches per English gallon) of total carbonic acid (7·22 cubic centimetres [2 cubic inches] in the combined and semi-combined and 7·77 cubic centimetres [2·15 cubic inches] in the free state), and 29 cubic centimetres (8·04 cubic inches) of dissolved air, of which 8 cubic centimetres (2·22 cubic inches) are oxygen.

The concentrate left in the boiler was examined; 100,000 parts of it were found to contain :

Total solid residues	315·20 parts.
These contained :	
Silica	13·70 —
Iron and aluminium oxides	0·90 —
Calcium sulphate	57·40 —
— nitrate	25·39 —
Sodium —	112·73 —
— chloride	39·89 —
Magnesium chloride	50·16 —

Small soda-pumps are now definitely connected with the water-supply pumps, adding to each cubic metre of water 110 grams (1·10 lb. per 1,000 English gallons) of soda mixture (9 parts of calcined sodiun carbonate to two parts of sodium hydroxide); moreover, at the point where the water leaves the supply pipe it flows on to a series of plates with grooves and fine holes, before it enters the tanks; it accordingly is broken up into a number of fine streams and falls, losing dissolved gases. The corrosion is sufficiently prevented by these measures.

At another place, the water was caught as surface water and pumped to the tank. Boilers fed with this water soon showed serious corrosion of the tubes, roof stays, rivets and walls at the level of the water. A moderate amount of scale was formed and the water was of moderate hardness. Chemical examination showed the absence of any injurious quantity of the ordinary mineral acids; but the water contained compounds of humic acid, which came from the layers of peat through which the water flowed and which could not be removed. This water supply was given up and water was obtained from deep wells.

Water is used at the stations at Güsten, Stassfurt, Bernburg and Oschersleben, in which no free acid is found on analysis.

The analysis of the water gives the following results, expressed in parts per 100,000. (See table at the next page.)

All these waters strongly corrode the boiler walls and smoke tubes, although no free mineral acid can be detected. The administration of the Prussian-Hes-

sian State Railway thinks that this is chiefly due to the large sodium-chloride content, or to the large sodium-nitrate content, respectively.

—	Güsten.	Stassfurt.	Bernburg.	Oschersleben.
Sulphuric anhydride, as calcium sulphate	138	342	...	?
Nitric anhydride, as sodium nitrate	None.	5	...	?
Nitrous acid	None.	None.	None.	None.
Ammonia	None.	None.	None.	None.
Chlorine	161	371	...	?
Alkalis, as sodium oxide	142	307	...	?
Iron, $Fe_2 O_3$	...	...	?	...
Potassium permanganate required	105	8	...	...
Calcium oxide	172	227·5	...	...
Magnesium oxide	63	110	...	?
Calcium sulphate	234	553	774	598
Calcium carbonate	136	...	82	121
Magnesium carbonate	132	184	161	196
Magnesium chloride	...	31	25	...
Sodium chloride	267	570	216	122
Sodium nitrate	...	8	119	84
Organic acids calculated as oxalic acid	122	9	8	4
Total hardness	20·02°	38·15°	...	44·66°
Scale-forming constituents	624	746	1,025	919
Total solid residues (including combined water), dried for two hours at 110° C. (230° Fahr.)	940	1,530	1,590	1,270

14. *Coating the insides of boilers.* — The different administrations have tried various means in order to present corrosion, but no one has any particular success to report. Painting the inside over with hot tar seems so far to give the best results.

The Bavarian State Railway carefully cleans any parts which are corroded and coats them with Portland cement; the Alsace-Lorraine Railway tins such places.

Many of the nostrums sold for preventing the formation of scale have proved useless, at least as far as locomotive boilers are concerned; some certainly act as solvents on any scale present, but also attack the walls of the boiler. An instance of this is shown in figures 94 and 95, which represent two pieces of hoop iron which recently remained twenty-seven and thirty-five days respectively in a boiler, between the throat plate and the tube-plate; the feed water had a disincrustant added which consisted of a thick extract of cutch (Acacia Catechu), which contained tannic acid. The corroded spots shown in the figures showed a clean metallic iron surface, and the holes were

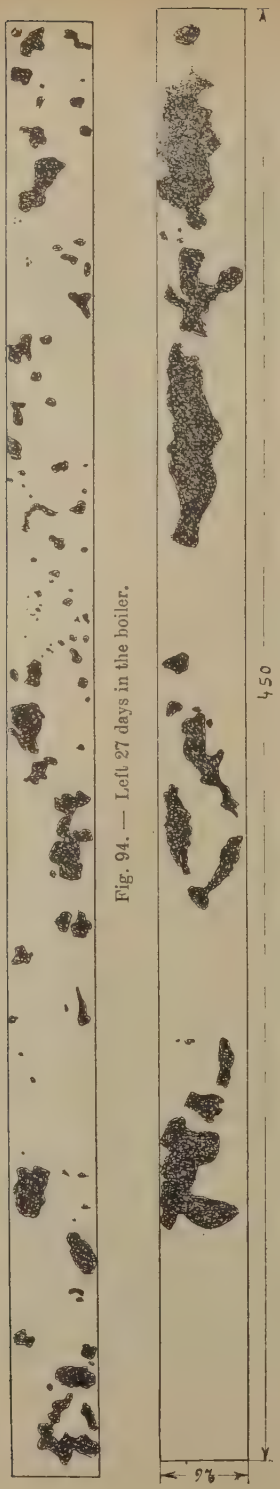


Fig. 94. — Left 27 days in the boiler.

Depth of corrosion, about 0·2 millimetre (1/128 inch).

Fig. 95. — Left 35 days in the boiler.

Fig. 94 and 95. — Hoop iron corroded by disincrustants.

about 0·2 millimetre ($^1/_{128}$ inch) deep. Strips of copper put in at the same time showed no traces of corrosion.

The Swiss Federal Railway and the St. Gothard Railway are at present making trials with coats of Siderosthene-Lubrose. The Prussian-Hessian State Railway and other railways are experimenting with coats of Palmaris, Delmatine and Anticorrosivum, without any success so far.

15. *Introduction of zinc plates.* — The Alsace-Lorraine Railway alone has tried zinc plates in boilers, in order to counteract the action of the chlorides, but without success.

16. *Stays.* — As a rule, bar copper is used for the stays, which has an ultimate tensile strength of at least 22 kilograms per square millimetre (31,290 lb. per square inch), an elongation of at least 38 per cent measured on a length of 200 millimetres (7 $^7/_8$ inches) and a contraction of area of at least 45 per cent of the original cross-section. In many recent cases, the front and back vertical rows of the stays of large fire-boxes are made of manganese bronze, which is generally specified to have an ultimate tensile strength of 30 kilograms per square millimetre (42,668 lb. per square inch), an elongation of 25 to 30 per cent measured on a length of 200 millimetres (7 $^7/_8$ inches). The manganese content is not to exceed 5 to 7 per cent. The Alsace-Lorraine Railway specifies that this bronze is to contain no tin, while the Danish State Railway specifies that this bronze is to contain 95 per cent of copper, 4·5 per cent of Banca tin and only 0·5 per cent of manganese, and emphasizes that stays with a greater manganese content give bad results. It is stated generally that the manganese bronze is stronger and hence less liable to fracture than copper. As regards burning away, it is stated to be

equal to, or slightly less resistant than copper.

The Dutch State Railway and the Swedish State Railway, besides manganese bronzes, use also Stone metal; the former finds no advantage in doing so.

The Prussian-Hessian State Railway, besides the metals already named, are also using the following experimentally:

a) Durana metal, which has an ultimate tensile strength of 33 kilograms per square millimetre (46,935 lb. per square inch), an elongation of 40 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches) and a contraction of area of 70 per cent.

b) Ingot iron. The trials so far made would seem to indicate that economic results are not obtained with this material, as this metal is more difficult and consequently more expensive to work than copper, and as the old scrap is worth exceedingly little.

c) Iron stays with a 5-millimetre ($^{3}/_{16}$ inch) hole, supplied by the Ohio Falls Company.

These trials are at present still going on.

Earlier trials made with nickel copper were discontinued, as the heads came off prematurely and the metal was very expensive to work. Rübel's bronze also proved unsatisfactory, as it burns away very quickly. After the heads have become burnt, it is impossible to get the stays tight. This bronze becomes so brittle during use, that the heads crack up during subsequent riveting and caulking operations. Moreover, after several renewals it became necessary to use stays having a diameter of 32 millimetres (1 $^{1}/_{4}$ inches); so that after two renewals it became necessary to use special bushes, and this not only reduces the strength of the fire-box but also shortens its life. Fractures and leaks occur as often as with ordinary stays, but only at the level of the fire; these defects are not observed in the upper seven or eight rows of stays.

Finally, experiments are being made with hollow-rolled round copper bar, the hole having a diameter of 5 millimetres ($^{3}/_{16}$ inch). As far as present experiments go, the heads wear less than with the ordinary stays. The stays also last longer. They are said to limit to some extent the development of smoke by the air entering through the hole. The trials which have been begun have not yet been completed; as far as they go they show that these stays are somewhat superior to others. Such copper stays are also used, on a more extended scale and with success, by the Dutch Railway Company, the Dutch State Railway and the Swiss Federal Railway.

Much trouble has not been given by the breaking of stays, as everywhere provision is made for the speedy renewal of any broken stays, so that the internal fire-box or the shell can probably not be endangered. Such fractures occur in most cases close to the plates of the internal fire-box or of the fire-box shell, usually in the radius just beyond the thread, seldom in the middle. Some of the administrations state that fracture is most liable to occur near the fire-box side, while others name the shell side.

The fractures are in most cases in the side walls within the zone of the fire and near the supports, and also in the upper rows of the side walls and of the back. They are rarer in the neighbourhood of the vertical corners and under the fire arch

in the side walls and in the bottom part of the fire-box tube-plate; the Alsace-Lorraine Railway however also mentions the latter point as one where fracture frequently takes place.

No special means are adopted for detecting fractures of fire-box stays except the usual holes, about 3 to 4 millimetres in diameter ($^1/_8$ to $^5/_{32}$ inch), which are drilled from either end of the stay to a depth of about 40 to 50 millimetres (1 $^9/_{16}$ to 2 inches), so that they extend beyond the threaded portion. In many cases holes, 15 to 18 millimetres ($^{19}/_{32}$ to $^{23}/_{32}$ inch) in diameter, are made through the sheet-iron lagging, opposite the stays, in order to facilitate the detection of fractures.

Flexible stay-bolts are only in use on the Danish State Railway (1). Then also the Norwegian State Railway, in the case of a few locomotives, has put in flexible stays in the last longitudinal rows of the roof stays, about 1 metre (3 ft. 3 $^3/_8$ in.) from the tube-plate.

Trouble from stay heads burning away and dropping off has not arisen anywhere.

Particulars of stays and their arrangement are also given in figures 45, 48, 51 to 61, and 64.

17. *The use of fire-bricks.* — The Saxon State Railway and the Swedish State Railway are the only ones who have tried fire-brick linings, but have given them up. The former states that the cost of repairing the linings was too high, and that they were moreover a source of danger should the walls collapse.

Most of the railways, however, use on their locomotives, to a greater or lesser extent, fire-brick arches of varying sizes and shapes to suit the locomotives in question, the object being to protect the tube-plate and prevent the formation of smoke. Good results are obtained.

Conclusions, question VI-C.

(Germany, Denmark, Holland, Luxemburg, Norway, Sweden, Switzerland.)

The chief boiler defects are :

1° *Cracks* at the top and side bends and in the interspaces of the fire-box tube-plate, at the bends of the fire-box shell and throat plate, at the places where the stays are fixed in the side plates and in the roof, at the riveting of the fire-hole, at the wash-out openings and in the side and roof stays.

2° *Pitting* in most cases is found in the bottom part of the plates of the barrel, particularly above the boiler supports and near the points at which the feed-water is delivered, to a height of about one third of the diameter of the boiler; frequently also, in the smoke tubes near the fire-box tube-plate.

3° *Grooving* is found in the fire-box shell plates immediately above the foundation ring, in the lower part of the smoke-box tube-plate, and at the seams of the barrel; in this case the grooves are generally parallel to the caulking line.

4° *General surface corrosion* is found in the lower half of the barrel, on the outside of the boiler at the wash-out holes

(1) Vide *Bulletin of the Railway Congress*, No. of January, 1904, p. 44 : « Stays of adjustable length for locomotives of the Danish State Railways », by O. Busse.

and at the seams of the rings of the barrel.

In order to counteract such defects, prevent the deposit of scale and preserve the boiler as much as possible, the best measure is generally considered the purification of the feed-water *before* it is used, the hardness being reduced to 6 or 8 German degrees of hardness.

The different processes of chemical treatment in special plants produce suitable softening and give good economic results. In the case of water which does not contain too much scale-forming content, it suffices if chemicals, especially sodium carbonate, are added to the water in the boiler or in the tender.

In both cases, the quantity of sodium carbonate added must be carefully checked, in order to avoid resulting disadvantages.

The many other remedies for preventing the formation of scale, which have been frequently recommended and tried have not given any good results, except in the case of petroleum.

Devices for separating the scale inside the boilers such as those of the Rhetian Railway or of the Gölsdorf design act favourably and appear to indicate a method for the further reduction of the trouble caused by the formation of hard scale.

In order to avoid any disadvantages, both from the economical and from the operating points of view, the boilers must be properly made at the boiler shops and the quality of the metal must be carefully checked; the most important thing then is that the boilers should be properly treated while in use, and above all carefully washed out and cleaned. The expense this involves is much more than counterbalanced by the reduced cost of upkeep and the increased length of life of the boiler.

Washing out with hot water is preferred by the majority of the administrations.

The metal chiefly used for stays is copper; but manganese bronze has also in many cases given good results at points which are not too much exposed to the fire.

All the administrations concerned think that there is no occasion for any material alteration in the present design of boilers, in order to prevent boiler defects.

APPENDIX I.

Index number.	Name of railway.	Class of locomotive.	Grate area, in square metres.	Heating surface.		
				Fire-box, in square metres.	Smoke tubes, in square metres.	Total, in square metres.
1	Prussian-Hessian State Railway.	2/4 wet-steam compound two-cylinder for express trains	2 27	9·06	109·01	118·07
2	Ditto	2/4 superheated-steam twin for express trains	2·27	10·56	91·15	101 71
3	Ditto	2/5 wet-steam compound four-cylinder for express trains	3·00	10·83	167·96	177·96
4	Ditto	2/4 wet-steam compound four-cylinder for express trains	2·28	11·35	110·61	121·96
5	Ditto	2/4 superheated-steam twin for express trains.	2·30	11·83	126·87	138·70
6	Ditto	2/5 wet-steam four-cylinder compound for express trains	2·71	..	...	162·9
7	Ditto	2/5 wet-steam four-cylinder compound for express trains	2·71	...	...	234·0
8	Ditto	2/4 superheated-steam twin for express trains.	2·31	...	...	131·32
9	Ditto	2/4 wet-steam compound for express trains.	2·27	...	...	125·00
10	Ditto	2/4 superheated-steam twin with Pielock superheater for passenger trains.	2 25	11·54	160·08 superheater tubes included	171·62
11	Ditto	4/4 wet-steam compound for goods trains	2·25	10·02	128·7	138·72
12	Ditto	4/4 superheated-steam twin for goods trains	2·25	11·97	120·29	132·26
13	Ditto	3/4 wet steam twin tank locomotive for goods trains	1·53	7·17	100·77	107·94
14	Ditto	3/3 superheated-steam twin tank locomotive for goods trains	1·48	7·53	60·90	68 43
15	Ditto	3/4 wet steam twin tank locomotive for passenger trains	1·70	8·43	112·07	120·50
16	Ditto	3/4 superheated-steam twin tank locomotive for passenger trains	1·73	9·33	102 64	111·97
17	Ditto	5/5 wet-steam twin tank locomotive for goods trains	2 37	8·39	129·13	137·52
18	Ditto	5/5 superheated-steam twin tank locomotive for goods trains	2·25	11·49	123·43	134·92
19	Ditto	2/5 wet-steam four-cylinder compound for express trains	4·00	...	...	253·0
20	Ditto	2/5 superheated-steam twin for passenger trains	2·62	14·24	136·28	150·52
21	Bavarian State Railway	2/5 wet-steam twin tank locomotive.	1·96	...	...	107
22	Ditto	2/5 superheated-steam twin tank locomotive	1·95	...	...	89
23	Ditto	2/4 wet-steam twin for passenger trains.	2·2	...	...	120·5
24	Ditto	2/4 superheated-steam twin for pasenger trains	2 2	...	...	94·6
25	Ditto	3/5 wet-steam four-cylinder compound for express trains	3·27	...	...	205 5
26	Ditto	3/5 superheated-steam four-cylinder compound for express trains	3·27	...	...	162·5
27	Dutch Railway Company	2/4 wet-steam twin for express trains	...	9·8	103·9	113·7
28	Ditto	2/4 superheated-steam twin for express trains.	...	10·3	73·1	83·4

APPENDIX I.

Surface of superheater, in square metres.	Working pressure, in atmospheres.	Diameter of cylinders		Stroke of pistons, in millimetres.	Diameter of driving wheels, in millimetres.	Maximum speed, in kilometres per hour.	Weight, empty, in tons.	Adhesive weight, in running order, in tons,	Total weight, in running order, in tons.
		High pressure, in millimetres.	Low pressure, in millimetres.						
...	12	400	680	600	1,980	100	46·3	30 3	59·58
30·75	12	530	...	600	1,980	100	48 8	29·9	53·20
...	16	340	560	640	1,980	100	57 6	29·4	63·10
...	14	340	530	640	1,980	100	52·6	32·1	57·30
38·57	12	550	...	630	2,100	110	53·4	34·1	59·50
...	14	360	560	600	1,980	100	54·68	31·4	60·00
...	14	360	560	600	1,980	100	56·46	29·9	61·82
31·69	12	550	...	630	2,100	110	53·7	32·61	59·00
...	12	460	680	600	1,980	100	43·15	30·00	48·32
26·52	12	540	...	630	1,600	90	52 00	45·00	58 00
...	12	530	750	630	1,250	45	48·21	54·73	54·73
31·70	12	590	...	600	1,350	50	50 45	56·00	56·00
...	12	430	...	630	1,350	60	41·53	40 96	53·40
16·40	12	500	...	600	1,350	60	37·0	46 2	46.2
...	12	480	...	630	1,500	80	49·2	47·25	63·00
29·5	12	540	...	630	1,500	80	51·5	47·10	65·10
...	12	520	...	630	1,200	45	60·3	73·50	73·50
41·91	12	610	...	660	1,350	50	59·65	74·3	74·30
...	14	380	580	600	1,980	100	68·8	33·0	76·90
48·98	12	590	...	630	1,750	100	63·6	46·76	69·53
...	12	450	...	500	1,640	...	52·8	...	...
20·2	12	500	...	560	1,640	...	54·4	...	...
...	12	430	...	610	1,860	...	44·5	...	...
26·8	13	490	...	610	1,870	...	47·1	...	...
...	16	340	570	640	1,870	...	63·7	...	...
34 5	16	360	590	640	1,870	...	64·9	...	...
...	10	457	...	660	2,016	...	...	...	...
22·3	10·2	550	...	660	2,016	...	...	...	...

APPENDIX I.

Index number.	Name of railway.	Class of locomotive.	Grate area, in square metres.	Heating surface.		
				Fire-box, in square metres.	Smoke tubes, in square metres.	Total, in square metres.
29	Swedish State Railway	2/4 wet-steam twin for express trains	1·97	8·26	89·7	97·6
30	Ditto	2/5 superheated-steam twin for express trains.	2·60	11·80	121·20	133·0
31	Ditto	3/5 superheated-steam twin for express trains.	2·60	12·7	140·0	152·7
32	Ditto	4/4 superheated-steam twin for goods trains	2·08	10·7	92·6	103·3
33	Ditto	5/5 superheated-steam for goods trains	3·15	13·1	183·0	196·1
34	Ditto	3/5 superheated-steam twin tank locomotive, for passenger trains	1·84	8·05	71·0	79·05
				Heating surface (in contact with water).		
35	Swiss Federal Railway	2/4 wet-steam two-cylinder compound for express trains	2·2	10·4	118·1	128·5
36	Ditto	3/5 wet-steam four-cylinder compound for express trains	2·6	15·5	143·1	158·6
37	Ditto	3/5 superheated four-cylinder compound for express trains	2·6	15·5	119·6	135·1
38	Ditto	3/5 wet-steam four-cylinder compound for express trains, with Brotan fire-box	2·5	18·0	159·0	177
39	Ditto	3/5 superheated-steam three-cylinder for express trains	2·6	15·5	119·6	135·1
40	Ditto	3/4 wet-steam three-cylinder compound for passenger trains	2·3	12·3	123·5	135·8
41	Ditto	3/4 superheated-steam twin for passenger trains	2·3	12·3	99·6	111·9
42	Ditto	4/5 wet-steam four-cylinder compound for goods trains	2·44	14 2	160·0	174·2
43	Ditto	4/5 superheated-steam twin for goods trains	2·44	14·2	126·8	141·0
44	St. Gothard Railway	3/5 superheated-steam four-cylinder compound for passenger trains, with Pielock superh.	2·4	12·8	114·0	126·8
45	Ditto	3/5 wet-steam four-cylinder compound for passenger trains	2·4	12·8	143·0	155·8
46	Ditto	3/3 superheated-steam twin for goods trains, with Pielock superheater	2·08	10·2	94·8	105·0
47	Ditto	3/3 wet-steam twin for goods trains	2·08	10·2	122	132·2
48	Ditto	4/4 superheated-steam twin for goods trains, with Pielock superheater	2·15	11·56	122·38	133·94
49	Ditto	4/4 superheated-steam twin for goods trains, with Schmidt smoke-tube superheater	2·15	11·50	113·8	125·3
50	Ditto	4/5 superheated-steam four-cylinder compound, for goods trains, with Clench superheater	4·07	13·15	220·0	233·15
51	Ditto	3/5 superheated-steam four-cylinder compound, for passenger trains, with Clench superh.	3·34	15·4	173·2	188·6
52	Rhetian Railway	4/5 wet-steam two-cylinder compound for goods trains	2·1	8·4	123	131·4
53	Ditto	4/5 superheated-steam twin for goods trains	2·1	8·4	97·1	105·5

APPENDIX I.

Surface of superheater, in square metres.	Working pressure, in atmospheres.	Diameter of cylinders		Stroke of pistons, in millimetres.	Diameter of driving wheels, in millimetres.	Maximum speed, in kilometres, per hour.	Weight, empty, in tons.	Adhesive weight, in running order, in tons.	Total weight, in running order, in tons
		High pressure, in millimetres.	Low pressure, in millimetres.						
...	11	420	...	559	1,880	90	37.4	26·5	41·10 47 p. c. coal economy.
2·80	12	500	...	600	1,880	90	54·7	30·9	60·2
4·5	12	590	...	600	1,750	90	62·3	47·4	68·5
8·0	12	500	...	640	1,388	...	45·5	50·0	50·0
8·9	12	700	...	640	1,300	...	75·5	83·5	83·5
0·45	11.5	500	..	580	1,530	...	47·4	40·0	60·00
...	13	460	680	660	1,830	90	46·2	31·8	51·0
...	15	360	570	660	1,780	100	58·0	46·0	64·4
7·6	13	425	630	660	1,780	100	62·7	45·7	68·9
...	15	360	570	660	1,780	100	58·6	45·7	65·1
7·6	12	3×470	....	660	1,780	100	60·5	45·4	66·8
...	14	500	2×540	600	1,520	75	50·4	44·8	56·4
8·6	12	540	...	600	1,520	75	50·5	45·1	56·3
...	14	370	600	600	1,330	65	59·7	57·6	66·3
7·6	12	570	...	640	1,330	65	60·4	58·0	67·1
9·0	15	370	600	660	1,600	90	60·72	...	...
...	15	370	600	600	1,610	90	59·57	...	...
7·2	12	480	...	640	1,330	55	43·9	...	...
...	12	480	...	640	1,330	55	42·8	...	...
6·86	15	520	...	630	1,230	45	54·67	...	...
3·4	15	520	...	630	1,230	45	55·07	...	...
5·0	15	395	635	640	1,350	65	71·0	...	...
7·4	15	395	635	640	1,610	90	73·3	...	...
...	14	440	660	580	1,050	45	42·12	41·6	47·0
7·5	12	460	...	580	1,050	45	42·12	41·6	47·0

APPENDIX II.

ADMINISTRATION OF THE PRUSSIAN STATE RAILWAY.

Instructions for the treatment of the superheated-steam locomotives in practice.

I

Special equipment of the superheated-steam locomotives.

1. A *smoke-box superheater* to which the hot gases are supplied by a flue tube passing through the barrel; or,

A *smoke-tube superheater*, each element of which is placed in a large smoke tube, through which the hot gases giving the superheat pass.

2. *Damper-actuating* gear for the *smoke-box* superheater, connected with the blast-regulation gear; or,

Automatic *damper gear* for the *smoke-tube superheater*.

3. A *blow-off valve*, which is used for cleaning the *smoke-box* superheater by means of air or steam; or,

A device for blowing out the large smoke tubes, in which the superheater elements are contained, consisting of a metal hose and jet, which can be connected with a supply of compressed air or of steam.

4. A special *second ashpan* in the case of the smoke-box superheater in order to remove cinders from the superheater.

5. A *cleaning door in the smoke-box*, through the opening of which it is possible to clean out the flue tube in the case of the smoke-box superheater, and to clean the lower part of the superheater tubes.

6. At *the cylinders :*

a) *Piston valves* with internal admission without spring rings.

b) *Safety valves* and *air-admission valves* in the bottom and top cover of the cylinder, as well as *safety valves* in connection with the drain-cocks.

c) A *pressure-equalizing device* with actuating gear, for running with ventilator closed.

d) A *guide* for the tail rod of the piston.

7. An *oil press* instead of the displacement lubricator.

8. A *distance pyrometer* to indicate the temperature of the superheated steam in the valve chest.

9. A *valve-chest pressure-gauge*, which shows the working pressure of the superheated steam in the valve chest.

10. A *vacuum gauge*, for indicating the vacuum in the smoke-box.

II

General instructions on the handling and driving of superheated-steam locomotives.

1. *At starting*, the regulator must never be opened suddenly. Even under heaviest load it must only be opened to such an extent, that the pressure in the valve chest is at least half an atmosphere below that of the boiler in order to prevent any water from being carried over into the cylinders.

2. *To prevent the engine from slipping*, the valve motion is to be notched back as soon as the pull has begun, and the starting is to be controlled principally by it. The easy movement of

the motion makes it possible, *even when the regulator is open, to control the motion at starting by hand, and setting the cut-off at every moment in such a position that slipping is avoided while maintaining as powerful a starting pull as possible.*

3. *Position of regulator and valve gear.* The cut-off is never to be set below $^2/_{10}$, even when the pressure in the valve chest is normal. If less power is required, the cut-off must not be set below $^2/_{10}$, but the steam pressure in the valve chest must be reduced, from 11 $^1/_2$ to 3 atmospheres, as may be required, by throttling with the regulator, and the cut-off advanced, according to the reduction of pressure, so as to ensure easy running.

4. *Conscientious treatment of the oil press.* (See III-1, IV-4 and V-5).

5. *Cleaning* and attending to the *superheater.* (See IV-2 and 3 and V.)

6. *As great a superheat as possible.* (Compare III-4 and IV-1 and 2.)

The average superheat must be kept as nearly as possible at 320° C. (608° Fahr.) and must not exceed 350° C. (662° Fahr.) for any length of time. The temperature of the superheated steam is indicated by the distance pyrometer.

Insufficient superheat, under ordinary working conditions, is obtained with a *large smoky fire* or with *too low a fire* on the grate when the hot gases become cooled by excess of air; also if the superheater has not been properly cleaned and *if the brick arch is too long or placed too high, so as to impede the free access of the flames to the flue tube.* Insufficient superheat is also caused by too high a water-level.

A sudden drop in the temperature of the superheat indicates that water has been carried over into the superheater; this may happen repeatedly with foaming or dirty feed water and can only be remedied by thoroughly washing out the boiler. Careful use of the regulator, and corresponding throttling of the steam, help in obtaining a good superheat, because the steam from the boiler then reaches the superheater in as dry a condition as possible.

The proper degree of throttling is ascertained from the indications of the valve chest pressure-gauge, which show the driver what working pressure he is using.

7. *Careful treatment of the valve gear. On shutting the regulator, the valve gear may not be laid off immediately.* In order to make sure of preventing jamming and cutting, the valve gear must only be set for starting after the locomotive has been completely stopped.

In all cases when coming out of the sheds, however, the gear must be set full forward, so that the valves travel over the whole length of the liner and remove any coom or dirt which may have collected.

8. *Use of the pressure equalizer.* The gear which is on the driver's side *must at once be operated when the regulator has been closed, and immediately shut again when the locomotive stops,* without altering the position of the valve gear (1).

III

Before starting.

1. *The oil press,* in accordance with the instructions for its use, which must be on the locomotive, is to be filled regularly with special oil at the ends of the journey. *It must inva-*

(1) In the case of all those superheated-steam locomotives *which have cylinders which have not been fitted with any pressure-equalizing device,* it is necessary, in order to obtain smooth running on down gradients, not to close the regulator entirely, but to run with the reduced pressure in the valve chest, corresponding to the gradient in question, and with the cut-off set in that position, in which smoothest running is obtained at the different speeds. Should the speed become too high, it is easy to apply the brakes.— The piston valves and steam pistons then do not draw in dirt and soot from the smoke-box, the cooling of the cylinders is avoided, the fire is kept in good condition by the moderate vacuum, and the grate does not become obstructed by clinker.

riably be tested by hand before starting on a journey as to its working condition. The strainer in the feed vessel must be cleaned frequently. The press must be kept scrupulously clean. Only special oil is to be used.

The *Michalk* oil press only supplies oil *for lubrication, when the conical plug is in such a position, that the key can only be turned to the right.* The key is to be taken off at the end of the journey after the press has been filled, to prevent any tampering.

In the case of the *Dicker and Werneburg oil press* the key must be pressed down after filling the container. The rate at which the emptying of the press is proceeding can be observed by the rotation of the cap in the middle of the press. As soon as all the oil has been used the key jumps up automatically and the press must then *at once* be filled again; this will happen if the press has not been filled properly before the start.

In the case of the *Ritter* press the oil is only automatically supplied as long as the wing nut is screwed down tight on the coupling spring. In order to test the press, *for delivery of oil*, by hand, the wing nut is loosened and the *key turned to the left.*

In order to *fill* the press, the wing nut is loosened and the *key turned to the right.*

Oiling by hand while running is as a rule to be avoided and only advisable when the locomotives are doing very heavy work or when the superheat is above 350° C. (662° Fahr.) or if the valve gear is not working smoothly. In the latter case the cut-off is at once to be set to the zero point and only slowly moved forward again when the running is perfectly smooth.

2. The damper flaps which are in connexion with the *blast-regulation gear*, in the case of the *smoke-box superheater*, are always to be kept shut, on account of the soot, while firing up, and are only to be opened when there is a bright fire, just before starting.

The *automatic damper flaps of the smoke-tube superheater* must also be carefully closed while firing up the locomotive or standing still; they must be kept carefully clean.

Their adjustment in order to regulate the superheat is only to be effected when the regulator is opened, and in accordance with the directions given on an indicator plate.

3. *The tightness of the smoke-box is of very great importance.* All the joints must be carefully examined. Any leakages in the door, the covering plates, the flanges of the two ashpans and their fastenings must be very carefully stopped, as such leakages have a very prejudicial effect on the working of the superheater and consequently on the economy and power of the locomotive.

4. Before *starting*, the cylinders should be warmed and the water must be allowed to escape through the drain cocks. After starting these cocks are only to be closed when the valve chest and cylinder have become heated sufficiently, the pyrometer indicating 200° C. (392° Fahr.) or more. Afterwards the cocks may remain closed even at starting; but they must be immediately opened if there is any sudden drop in the superheat, for the first conclusion to be then drawn is that the water has been carried over into the superheater or into the cylinders.

5. *The springs of the safety valves* on the cylinders must always be kept free from dirt, in order that they may retain their free play, and the safety valve accordingly retain its efficiency.

6. The nuts for the adjustment of the valve gear at the cross-heads of the valve rods as well as their securing devices must be examined before each journey to see that they are tight.

IV

During the journey.

1. The fire is to be regulated in such a way, that the superheat should be 320° C. (608° Fahr.) as near as possible, on the average; this is effected by having a depth of well-ignited fuel

over the whole of the grate, and adding fresh coal by a few shovelfuls at a time in a horseshoe shape, *i. e.*, making the chief additions at the back and in the two back corners of the fire-box and below the fire-door.

It is consequently absolutely necessary that the firing shall be done more frequently than with compound locomotives, and as a rule water should be pumped up after each firing. But the fire must never become low enough to reduce the temperature of combustion or allow cold air to penetrate through bare spots on the grate into the fire-box.

2. If under favourable conditions *the temperature* of the superheater *rises* to 350° C. (662° Fahr.), the superheater damper flaps are to be closed to such an extent that this superheat is not materially exceeded.

3. If the locomotive is making a long run or doing very heavy work, the *smoke-box sprinkler* should frequently be opened for a very short time, in order that the different superheated parts and covering plates may not be injured by contact with the cinders in the smoke-box.

4. *The operation of the oil press* has to be watched and its operating gear has to be *lubricated* in *accordance with the instructions.*

5. *After closing the regulator the equalizer gear must at once be operated; the cut-off is left however set as it is, and must not be moved till after the locomotive has stopped.* In this way the whole motion works smoothly when running with regulator closed; the locomotive runs more smoothly and the admission valves on the bottom and top cover of the cylinders prevent any soot from being drawn in from the smoke-box and dirtying the piston valves (1).

6. *When one side of the locomotive is out of action,* the motion on this side has first of all to be set into the zero position, so that both admission ports in the cylinder are closed. Then the following work has to be done : *the crank pin on this side is to be set vertically* at *the top* or at *the bottom, the valve gear is to be placed centrally,* the *connecting piece* of the cross-head and the guide lever, as well as the *return crank rod*, have to be *taken off.* The *guide lever has to be set truly vertical.* The valve is then in the central position and the *valve rod* is to *be fixed* in this position by the screws supplied.

Moreover the *rod actuating* the *drain cocks of the cylinder* in question has to be *uncoupled* and *fixed in such a position,* that the cocks are open, so that any steam which may enter the cylinder owing to want of tightness of the valve, can escape.

Taking off the coupling rods and *fixing* the *cross-head* and *piston* is only necessary if one of these parts has become *damaged* or if a *longer journey has still to be made.*

V

After the journey.

1. The cinders have to be taken out of the ashpans and the clinker on and between the grate bars has to be carefully removed.

2. The superheater must be thoroughly blown out and cleaned.

It must be blown out every time a journey has been completed, in the case of the smoke-box superheaters in the first place with the superheater damper flaps open, and *after the cinders have been removed,* with the ashpan open and the superheater damper flaps closed.

In the case of *smoke-tube superheaters* the blowing out is to be effected by screwing the blowing-out hose to the steam supply or to the compressed-air supply, introducing the jet of the hose at the back end of the smoke tubes.

During the washing out, any accumulations of slag that may have formed on the caps of the

(1) On long down gradients it may happen, in the case of the older equalizers, which are too small, that the compression will become too great and the cylinder become heated. In such cases it is allowed to advance the cut-off slowly.

superheater elements are to be knocked off from the fire-box side and removed.

Any obstruction is to be removed by a tube running rod.

3. The superheater damper flaps and the covering plates of the two ashpans are then to be cleaned carefully and the latter secured tight.

4. The springs and covers of the safety valves of the cylinders are to be cleaned.

5. During the washing out the spark arrester is to be taken out in order to see if an incrustation of soot has formed on the rim of the blast pipe. If this is the case, there was excessive lubrication and the stroke of the oil press must be reduced. The incrustation of soot, which interferes with the draft, has to be carefully removed, *so that no soot can fall into the exhaust tube.*

Washing out or sprinkling the superheater is absolutely forbidden, for it leads to the rusting of the pipes.

These instructions were established by the Minister of Public Works by order of 17 May 1906, VI, D. 9160, for all the directorate districts, and are in accordance therewith hereby issued by the undersigned administration.

APPENDIX III.

Detailed list of questions relating to question VI.

A. — BOILERS WITH SMOKE TUBES; PRECAUTIONS IN CONSTRUCTING AND MAINTAINING TUBES AND TUBE-PLATES.

1. What type of boiler do you use? Belpaire or round-topped? Please forward drawings of your latest standard types.

2. If you use round-topped boilers, do you use roof-bar or radial stays on the fire-box crown sheets? Kindly state what special advantages you find from each type.

3. Have you any locomotives fitted with cylindrical fire-boxes? If you use this type, please submit drawings and describe the advantages or disadvantages derived from the use of this design.

4. Are any of your boilers fitted with combustion chambers? If so, please supply drawings and state what results have been obtained with this method of construction.

5. Have you constructed any boilers with fire-boxes of any other material than copper? If so, what have been the results compared with copper fire-boxes of the same design.

6. What shape and size of firehole do you find the most suitable? Do you employ any special means of air admission? Do you use a ring joint or dished joint between the inner fire-box plate and back plate? If the former, how is it fastened, and if the latter, how are the plates joined? Kindly send drawing and state your experience as regards the maintenance of the tightness of the joint made.

7. What is the proportion between the total grate area, air-space in the firegrate, and total tube area? Are any of your boilers fitted with rocking or drop grates?

8. In very long boilers, do you employ any form of intermediate support for the barrel of the boiler?

9. Which type of front tube-plate do you fit your boilers with, *viz.*, drum-head, or plate with extension fitted to the cylinder casing?

10. What material are your tubes constructed of? Give reasons for the adoption of the metal or alloy you employ.

11. What are the dimensions of tubes used in your chief types of boiler, including thickness at each end?

12. What is the method employed in fixing tubes in your boilers? Kindly give a description, with sketches, of any special machines or device employed for this purpose. Are the tubes expanded and contracted by any special method?

13. Have you had any experience with Serve tubes? If so, please supply particulars.

14. Are you troubled with

a) Pitting of steel or iron tubes?

b) Excessive wear or fracture of copper or brass tubes just inside the copper tube-plate?

What steps do you take to counteract these defects? Have you tried galvanized steel or iron tubes, and, if so, with what results? Have you used iron or steel tubes with copper ends at the fire-box tube-plate? If so, what is the length of the copper ends, how do you join the ends to the

tubes, and what results have been obtained with these ends as regards the durability of the joint, the reduction of corrosion and the tightness of the joint in fire-box tube-plate?

15. Do you employ ferrules in tubes? If so, with what object in view, *e. g.*,

a) Keeping the tube tight?
b) Protecting the end of the tube from the action of the fire?

What taper and thickness of ferrule do you use? Do you bead the ends of your tubes and, if so, with what results? If this has been tried and given up, what cause led to its being discontinued?

16. How are your tubes arranged in the tube-plate, i. e., in vertical or horizontal rows? State the reason for your practice. What space is allowed between the tubes?

17. Do you employ pressures above 180 lbs. per square inch and, if so, have any special means had to be taken to cope with these pressures, especially in the keeping of the tubes tight and in maintaining the fire-box tube-plate in good condition?

18. Has it been found that any special spacing of the tubes or stays has led to a decrease in the trouble experienced from cracked corners of the tube-plate? Have you tried cold hammering of the copper tube-plate in order to harden it and, if so, with what results?

19. Do you use an extended smoke-box? If so, what advantages are derived from it. What devices have you fitted in the smoke-boxes or chimneys in order to prevent the ejection of sparks or to reduce their power of setting any thing alight? Kindly add drawing and state what results have been given by these devices, also as regards any possible bad influence on the maintenance of a proper draft?

20. In your latest standard types of boilers do you fit a steam-dome and, if not, what device is in use to obtain dry steam?

21. What material is used for lagging your boilers? Is a special layer of non-conducting material placed inside the sheet-iron lagging? If you have made any tests to ascertain the relative efficiency of different lagging materials, kindly give particulars and results.

22. Do you employ any system of thermal storage and, if so, what advantage do you derive from it?

23. Have you any mechanical-stoking devices in use, or have you tried any? If so, kindly state what fuel was used and what results were obtained, and give drawing.

B. — Boilers with water tubes. Steam superheaters and valve gear for superheated steam. Feed water heaters.

a) *Boilers with water tubes.*

1. Do you use water-tube boilers on your system? What advantages have been gained by substituting them for fire-tube boilers? How do the water-tube boilers work in comparison with fire-tube boilers? Is it possible with water-tube boilers to increase the heating surface more than with fire-tube boilers, by lengthening the boiler barrel?

2. Do you use water-tubes in the fire-boxes of your locomotives? Do the results obtained justify the increased expenditure incurred by putting them in and maintaining them?

3. Kindly furnish us with drawings of the methods you employ in both the above cases.

4. Have you made any analyses of the smokebox gases to ascertain what effect, if any, the water-tubes have in preventing complete combustion? If so, please state the results.

b) *Steam superheaters and valve gear for superheated steam.*

1. Do you employ superheated steam? If so, kindly give a description, with drawings, of any system you use.

2. What valve gear is used on your superheated-steam locomotives? Do you use :

a) Flat slide valves, relieved or not;
b) Piston valves;
c) Poppet valve gear?

Kindly give description and drawing. What pattern of valve gear do you prefer for superheated-steam locomotives?

3. What means do you employ of ensuring tightness with freedom of movement of the pistons and valves? Please give detailed drawings. Do you use piston valves with solid rings or with spring rings? What are the reasons in favour of either system. Do you use equalizers for equalizing the pressure on both sides of the piston? If so, what advantages have you obtained by the use of this device? Do you use safety valves and air-admission valves on your cylinders? If so, kindly state results and give drawings.

4. Give a description, with drawings, of the packing employed for the piston and valve rods. If metallic packing is employed, give the composition of the metal or alloy used.

5. Give drawing of the piston rod, including the cross head and tail rod, shewing the method of fixing the piston on the rod. Of what metal do you make the pistons, and of what metal do you make the piston rings and the walls or liners of the cylinders? Do you grind the piston rods, either when new or when under repair?

6. How long have you used superheaters? How many locomotives so fitted have you in service or under construction?

7. Have you used superheated steam for compound locomotives? If so, do you superheat the high pressure or low pressure steam, or both? Give drawings shewing the means adopted for superheating the high pressure or low pressure steam, or both.

8. Have you made any experiments for determining the effect of superheating? If so, kindly state :

a) the saving in water and coal,
b) the additional power and any other advantages realised.

What is the maximum superheat obtained when the locomotive is working at its greatest power. Hauling trains of different types. Please, also, give with these results, a comparative table shewing the principal dimensions of locomotives with and without superheaters including,

Grate area,
Heating surface and superheating surface,
Weight of locomotive — light,
Working pressure of the boiler,
Size of cylinders, etc.

Further, if you have experimented with simple-expansion or superheated locomotives in comparison with compounds, please give the results and principal dimensions of the engines between which the comparison was made. Have you been able to reduce the weight of the two-cylinder simple locomotive, using superheated steam, to that of the compound locomotive of the same power using saturated steam? If so by how much?

9. Where do you measure the amount of superheat attained, and with what apparatus? What fall of pressure have you found between the boiler and the valve chest? Is the pressure of the steam when admitted to the cylinders higher than when saturated steam is used for the same boiler pressure? Have you found any definite relation between the degree of superheat, additional power, and economy obtained? Have you established any relation between the total heating surface and the superheating surface? Has the employment of the superheater enabled you to reduce the working pressure of the boiler?

What is the increase in the dimensions of the cylinders which you have adopted for the superheated locomotives?

9bis. Have simultaneous measurements of the temperature of the hot gases been made at different points in the fire-box, the smoke tubes, and the smoke-box, in comparison with the degrees of superheat obtained at given boiler pressures?

If so, kindly describe the method of taking these comparative measurements, the apparatus used and the results obtained.

10. What is the saving of fuel and increase of power obtained by the use of superheated steam in comparison with saturated steam on similar locomotives taken on the same mileage? To what extent, and in what respect have you found that the theoretical advantages of superheated steam deduced from its thermal and other physical properties, as compared with wet steam, have been realized in practice?

11. What increase has taken place each year in the time the locomotive is out of service for repair of the superheater, packings, etc.? What is the annual cost of the maintenance and repair of this apparatus? Has any part of the superheater caused you any particular difficulty? Is the superheater sufficiently accessible in case of repair? Have you observed any blocking up by ashes of the tubes or other parts of the superheater, or any excessive wear?

If you have made comparative trials with different superheater systems (smoke-box, smoke tube, Pielock and other superheaters), what system do you prefer as regards keeping up the superheat, cheapness of maintenance, safety and suitability of the design? Kindly state your reasons fully. With Schmidt's superheater, placed in the fire-tubes, have you found any distortion of the fire-box tube-plate between the bottom row of large tubes and the top row of small tubes?

12. What is the extra cost of oiling superheated locomotives? What class of oil do you use for the cylinders? State whether a pure mineral oil, or a mixture of mineral oil and fixed oil, and, if the latter, please give the composition. Please also give the viscosity, specific gravity, and any other characteristics which you have determined of the mineral oil. Do you use mechanical or sight-feed lubricators, and what type?

13. Have you given any special instructions to your staff concerning the management or driving of these locomotives, and as to the attention required by the pistons and slide valves? Attach a copy of these instructions. Have any accidents occurred or persons been injured in consequence of the use of superheaters? If so, kindly give particulars.

14. Do you recognize, generally speaking, the superiority of the superheated-steam locomotive to the wet-steam locomotive (twin or compound) as regards economic working? Do you recommend the extension of its use, and for what classes of work, especially as regards express and goods locomotives doing heavy work?

c) *Feed water heaters.*

1. Do you use feed-water heaters? If so, please furnish drawings and descriptions.

2. Do you employ injectors or pumps? Please describe the means adopted for preventing the water from attaining such a temperature as would impede the action of the pump or injector.

3. What advantages have you realized by the use of special feed-water heaters?

C. — Damage to boilers, pitting, grooving, and corrosion. Means employed to prevent this damage. Purification of water and disincrustants.

1. What process, or processes, do you use for softening water? Give particulars of the chemical treatment, stating what chemicals are used; and, without describing well-known

methods, give details of any special methods or apparatus you employ, or any special details connected with the working of the ordinary methods of treatment which you have found advantageous. What precautions are observed to ensure the treatment being properly carried out?

2. State whether you are satisfied with the results obtained and, if possible, give figures shewing the saving effected in :

1° Fuel;
2° Cost of cleaning and retubing boilers;
3° Cost of repairs to and life of boilers;
4° Cost of water (*i. e.* by being able to use water which can be obtained cheaply, instead of having to purchase expensive water of better quality).

3. How do you deal with waters of which the hardness is mainly or largely due to calcium and magnesium sulphates, chlorides or nitrates? Do you soften such waters, and if so, what precautions do you take to prevent priming of the boilers caused by sodium salts introduced in softening?

4. Have you used barium hydroxide, barium carbonate, or barium aluminate in softening water containing sulphates. If so, please give particulars, results and cost of treatment, and state whether you find it pays.

5. Have you made any attempt to ascertain the quantity of sodium salts present in the water of locomotive boilers when priming commences? If so, please give particulars and results of these experiments.

6. Do you use, or have you used, disincrustants placed directly in the boilers, instead of treating the water before use? If so, state the nature of the materials used, and the results obtained.

7. In connection with water softening or the use of disincrustants, have you been troubled with excessive leakage of boiler tubes or stays? If so, kindly give particulars, stating what you conceive to be the cause of the leakage and whether any and, if so, what means you have found effectual in preventing or lessening this leakage.

8. On what portions of the interior of the boiler do the following defects occur :

1° Cracks;
2° Pitting;
3° Grooving;
4° General surface corrosion.

9. When the boilers undergo heavy repairs, are any notes made on the repair sheets as to the defects mentioned in Question 8? Are sketches made of the damaged plates, stays or tubes, illustrating the actual nature, position and dimensions of the defects? If so, kindly supply some of these sheets chosen from amongst those giving the most characteristic defects.

10. What are the methods employed in the design and construction of boilers to prevent any of the defects referred to in Questions 8 and 9? Have modifications been carried out in the design of the boilers with this end in view? What is the breadth of the water-spaces in the fire-box? Where is the feed water delivered, and in what manner?

11. Are the boilers washed out with cold or hot water? What are the mean mileages between two washings out? In fixing these mileages, is account taken of the quality of the water? What is the time allowed for cooling down before the boiler is washed out with cold water? What pressure of water is used for washing out? If any system of washing out with hot water is employed, kindly describe this fully.

12. Is blowing off a portion of the warte under pressure resorted to in order to prevent the formation of deposit and to check priming? If this practice is carried out, at what time and after what intervals is it done? What means are adopted to remove the water? Shew by

sketches the position of the blow-off cock and its design.

13. If you have any waters which are specially corrosive to boilers, but which by analysis are not found to contain free mineral acid, please give analyses stated in parts per 100,000 shewing (if possible) the amounts of

Lime (CaO).
Magnesia (MgO).
Soda (Na_2O).
Alkalinity (as $CaCO_3$).
Sulphuric Anhydride (SO_3).
Nitric Anhydride (N_2O_5).
Chlorine (Cl).
Carbon Dioxide (CO_2), free.
Total Solid Matter at 130° C.

14. Have you tried to prevent corrosion by coating the insides of boilers with Portland cement or any kind of paint, or by treating the water with a definite excess of lime or other chemical to neutralize carbonic or other acid, or by introducing chemicals or other substances into the boilers? If so, please give full particulars and results.

15. Do you use zinc plates in your boilers? If so, explain, with sketches, the method of application and the results as regards

1° Prevention of incrustation;
2° Prevention of pitting and corrosion.

16. What metal or alloy is used or has been tried for fire-box stays; if any metal other than copper or iron, give composition. What advantages have been found to result from the use of these other metals or alloys? Is any trouble experienced with stays breaking; if so, please state where these fractures occur and indicate :

1° The position in the stay itself;
2° The position of the stays in the box.

Are any special means adopted to detect fractures? Is any type of flexible stay used? Are you troubled with stay heads burning away and dropping off in the fire-box? If so, what means have been adopted or tried to prevent this, and with what result?

17. Have you tried lining the fire-box or any part of it with firebricks or fireclay slabs to protect the stays and fire-box walls from the action of the fire and to promote better circulation of the water in the fire-box; if so, give results, and state the nature and composition of fire-resisting material used.

SECTIONAL DISCUSSION

Meeting held on 8 July 1910 (morning).

MR. GERSTNER, IN THE CHAIR.

The President. (In French.) — Gentlemen, we are now going to consider question VI. Seeing that there are many reporters, I think that we will in the first place hear the reporters who have dealt with littera *A*, and then draft and adopt conclusions relating to that part of the question; we will then proceed in the same way with littera *B* and littera *C*.

Mr. Steinbiss, *reporter.* (In German.) — In drawing up my report, I took as my basis the information supplied by the administrations of the German, Danish, Luxemburg, Dutch, Norwegian, Swedish and Swiss railways.

The administrations of the Chinese, Egyptian, Greek, Dutch Indies and Congo railways, as well as a number of smaller privately-owned railways did not send me any information.

A. — Boilers with smoke tubes; precautions in constructing and maintaining tubes and tube-plates.

1. *Type of boiler.* — The majority of the administrations prefer boilers with round-topped fire-box shell, which is directly connected with the circular cylindrical or conical last ring of the barrel.

Belpaire boilers are the chief boilers used on the Saxon State Railway; they are very usual on the Alsace-Lorraine Railway and many are also used on the Wurtemberg State Railway and the Dutch State Railway. The Prussian State Railway has 98 Belpaire boilers on its more recent locomotives; 22 are on $^2/_4$ four-cylinder express locomotives and 76 on $^2/_5$ four-cylinder express locomotives of the Grafenstaden type. Apart from this, Belpaire boilers, except on the Saxon State Railway, are but seldom used on new locomotives.

Boilers with raised round fire-box top are found on the more recent locomotives of the Luxemburg Prinz Heinrich Railway and of the Prussian Hessian State Railway, on the $^4/_4$ and $^5/_5$ tank locomotives of the Hagans type. Raised fire-box tops of other shapes are only found on older locomotives and are no longer used in the newer designs.

The usual form of narrow fire-box, placed between the frame plates, is every-

where retained. The length of this fire-box, measured at the grate, has become extended to 3·12 metres (10 ft. 3 in.). Wide fire-boxes, extending laterally beyond the frame plates, with short grate, of the American Wootten design, are used in several cases on the German and Danish railways for passenger and express locomotives, but are as yet wholly in the experimental stage ; trouble frequently arises owing to leaks at the smoke tubes and defects of stay-bolts and fire-box walls. Consequently, the clear width at the bottom, formerly 2,200 millimetres (7 ft. 2 $^5/_8$ in.), has been reduced to between 1,600 and 1,900 millimetres (between 5 ft. 3 in. and 6 ft. 2 $^{13}/_{16}$ in.), and the length has been increased in order to obtain the large grate area required; this seems to give better results. The wide fire-box is also being introduced on goods locomotives.

Inclined back walls of the fire-box and shell are frequently used in the newer designs, with-boxes between the frame plates and extending beyond them.

In this way larger grate areas, with lengths of 3 to 3·12 metres (9 ft. 10 in. to 10 ft. 3 in.), can be obtained without increasing the weight of the fire-box excessively.

The bottom connection between the fire-box and the shell is always made by a strong bar frame of rectangular section with a double row of rivets.

The Danish State Railway has for a long time been using seams with a single row of rivets which have given good results in the case of high domes. Mr. Busse, the general manager of that railway, has published a paper on this subject. Moreover, there is a tendency to have the fire-box walls straight, as little curved as possible.

Instead of the riveted ring used else where, the Prussian-Hessian State Railway has recently been using seamless rings, of the Ehrhardt type, with good results; good results have there also been attained, as on the Swedish State Railway, with boiler barrels with dome, with welded longitudinal seam. The latter railway has recently been using steel castings for the dome cover.

The illustrations in my report will enable you to note particulars of the dimensions and the details of the designs of the various types.

2. *Stiffening the fire-box crown and connexions with the shell.* — Radial or inclined roof stay-bolts are used in order to increase the stiffness of the slightly-curved fire-box crowns of the boilers of the Baden State Railway, the Dutch State Railway, the Swedish State Railway, the Dutch Railway Company, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway, and also on the $^4/_4$ and $^5/_5$ goods tank locomotives of the Hagans type, and on a few express locomotives of the Prussian-Hessian State Railway. In all other cases, the roof stay-bolts used are arranged vertically and in parallel rows longitudinally and transversely.

The stays in question are made of wrought iron, ingot iron and mild steel.

In order to increase the mobility of the tube-plate and to prevent cracks from starting at the front end of the fire-box roof, the front two or three rows of roof stays are replaced, on many boilers, by roof bars; on the Wurtemberg and on the Saxon locomotives, and in a few cases

also on other locomotives, the two or three front rows are connected with yokes fixed to the shell, so as to be movable.

Roof stay-bolts are as a rule preferred to roof bars because the stays are easy to make and put in, and the roof is more easily accessible for examination and for cleaning. They form a reliable connection between the inner fire-box and the shell, are lighter and allow the water to circulate more freely; scale accordingly deposits less than when roof bars are used.

3. *Cylindrical fire-boxes.* — Cylindrical fire-boxes are not used by any administration. The experiments made years ago on the Prussian-Hessian State Railway with cylindrical, fire-boxes of the Lentz type, corrugated, gave unfavourable results. In course of time they lost their circular shape, and collapsed, giving rise to explosions.

4. *Combustion chambers.* — Boilers with combustion chambers are not used by any of the administrations in question.

5. *Material used for fire-boxes.* — The fire-boxes of nearly all the locomotives are made of ordinary copper. A few administrations have made experiments with fire-boxes made of ingot iron, nickel copper and hard copper.

The Bavarian State Railway was supplied in 1900 and 1901 by the Baldwin Works, Philadelphia, with two goods locomotives and two express locomotives, which had fire-boxes made of ingot iron. The ingot-iron fire-boxes of the goods locomotives have had to be renewed after four years and then again after a further three years. The second time copper fire-boxes were substituted. As regards the express locomotives, the one had its iron fire-box replaced after three years by a copper fire-box, the other after six years.

Trials were also made with ingot-iron fire-boxes on the Saxon State Railway, during 1892-1902; in consequence of corrosion and pitting, these fire-boxes only had a short life.

The Dutch State Railway had one locomotive fitted with an ingot-iron fire-box as an experiment; but the results were not satisfactory.

Some time ago, a number of ingot-iron fire-boxes were used on the Danish State Railway, but they showed little durability and consequently no further experiments were made with them.

Experiments are at present being made there with iron tube-plates in copper fire-boxes, and also with fire-boxes made of "hard copper" and "special copper" supplied by the firm Heckmann of Duisburg.

The Rhetian Railway has fitted a copper fire-box with a tube-plate which is made of iron at the top and of copper at the bottom. The observations made up to the present show that the smoke tubes, both with and without copper ends, are more difficult to keep tight than with a tube-plate consisting wholly of copper.

The Prussian-Hessian State Railway has tried fire-boxes made of ingot iron and of nickel copper. Trials made with ingot-iron fire-boxes gave results which were so unfavourable, that it was decided already in 1896 that such fire-boxes should not be used. Their average life was only three years, and much less under unfavourable conditions, particularly with bad feed water; in one case the life was as little as six months.

Fire-boxes made of nickel copper, supplied by the firm Basse and Selve of Altena in Westphalia, were tried on a $^3/_4$ goods

tank locomotive and a $3/4$ goods compound locomotive.

The observations made up to the present seem to show that nickel copper is not a suitable material for fire-boxes, for although it costs more it offers no advantage. A new locomotive equipped with a nickel-copper fire-box costs 3,600 marks (£180) more than if the fire-box is made of ordinary copper; not only does the nickel copper cost more than the ordinary copper, but the work takes longer and costs more, as the metal is harder.

The Prussian-Hessian State Railway has also started negociations with a view to trying a fire-box tube-plate made of manganese copper manufactured by the Heddernheim Copper Works.

The ordinary copper used for fire-boxes is either smelted or obtained electrolytically; but it is still doubtful whether electrolytic copper is quite as good as smelted copper, as regards durability, and resistance to burning, particularly at the corners. The Prussian-Hessian State Railway specifies that the copper plate used for fire-boxes shall have an ultimate tensile strength of at least 22 kilograms per square millimetre (31,290 lb. per square inch) of original cross-section, and an elongation of at least 38 per cent, measured on a length of 200 millimetres ($7\ 7/8$ inches).

The metal to be tested may not be heated; the test pieces have accordingly to be cut and machined cold. Of late, arsenical copper is also used.

6. *Fire-doors.* — Most of the administrations are using single-wing swing doors; in a few cases, sliding doors in two parts, and exceptionally also drop doors opening inwards, in three parts, are used.

The doors are either circular, or oval, or rectangular with rounded corners.

The circular fire-holes vary in diameter from 300 to 450 millimetres ($11\ 13/16$ inches to 1 ft. $5\ 11/16$ in.), the oval fire holes and the rectangular fire-holes with corners rounded vary between 300 and 360 millimetres ($11\ 13/16$ in. and 1 ft. $2\ 3/16$ in.) in height and 375 and 500 millimetres (1 ft. $2\ 3/4$ in. and 1 ft. $7\ 11/16$ in.) in width. The smallest sizes found for circular doors are 300 millimetres ($11\ 13/16$ inches), on the Danish State Railway, and for rectangular doors, 300 × 375 millimetres ($11\ 13/16$ in. × 1 ft. $2\ 3/4$ in.), on the Saxon State Railway.

In the case of wide fire-boxes extending over the frame plates the doors are generally large and rectangular, with corners rounded, having a size of about 330 × 470 millimetres (1 ft. 1 in. × 1 ft. $6\ 1/2$ in.); or else double round or oval doors are used.

It often happened with locomotives with two fire-doors and an inclined back wall that owing to the high temperature at this wall the copper became burnt away, and it became necessary to put on patches. The substitution of one single door for the two doors will, it is hoped, prevent this.

The Baden State Railway has adopted since 1902, on its most recent express locomotives, fire-doors which are in three parts, which open inwards, turning up; two parts only are opened at once, the side piece taking the middle piece with it. The clear door opening is 390 × 700 millimetres (1 ft. $3\ 3/8$ in. × 2 ft. $3\ 9/16$ in.).

The Saxon State Railway attaches importance to small fire-holes, as but little cold air is admitted and the heating sur-

face is maintained, and uses a suitable shape of coal shovel to facilitate stoking. The Dutch State Railway considers sliding doors in two parts as the most suitable design; the Prussian-Hessian State Railway prefers the rectangular shape with rounded corners and the Alsace-Lorraine Railway considers the oval form best for a good uniform fire.

All the administrations have on some of their locomotives fire-doors with special devices for regulating air admission at the top; this air is to assist the air which enters between the grate bars in producing as perfect and as smokeless a combustion as possible. The fire-doors are as a rule fitted on the inner side with a cast-iron or wrought-iron protecting shield, which is kept red hot by the heat in the fire-box and warms the entering air which passes over it.

The new locomotives of all kinds on the German railways are in many cases fitted with the well known Marcotty and Langer smoke-consuming device (steam-jets above the grate); good results are obtained, as regards diminution of smoke, with this device (which works automatically) if properly looked after. A large number of fire doors is accordingly fitted with the circular grids necessary. The Rhetian Railway also uses that appliance. Staby smoke consumers, which are operated by opening and closing the ordinary fire-door, are also used, but only to a limited extent. Marcotty devices have also quite recently been fitted to the drop doors with lateral air admission on the Prussian-Hessian State Railway.

No information is supplied by the different administrations about trials of the numerous special devices proposed by many inventors for fire-doors and for improving the combustion.

The connection between the inner fire-box plate and the outer back plate, at the fire-hole, is generally effected, both when the back is vertical as well as when it is inclined, either by a wrought-iron fire-hole ring with a single row of rivets, which is of suitable shape, or else a dished joint is made between the two plates, with a single row of rivets (the Webb system). Neither method has given rise to leaks, but it is usual, in both cases, to use protective cast-iron rings or sheet-iron covers, which are added on the inner side, in order to reduce the action of the fire on the fire-hole joint, to prevent the burning of the rivet heads, and to protect them from being damaged by the firing tools.

The Prussian-Hessian State Railway, and also some other railways, are now trying a flat fire-hole ring, which does not require the same amount of dishing as the Webb system, but it is easier to keep tight than the strong fire-hole rings hitherto used, which had a length equal to that of the stay-bolts measured between plates.

The good results obtained with the fire-holes formed of dished joints are emphasized by most of the German railways, by the Danish State Railway and by the Swedish State Railway. The Swiss Federal Railway uses chiefly the flat fire-hole ring, riveted in.

7. *Ratio between total grate area, useful grate area and total tube area.* — The quality of the coal, the amount of heat produced by its combustion and the steam production of the locomotive in question determine the most suitable ratio between the total grate area R, the useful grate are R_f (*i. e.* the clear space between the

grate bars) and the total heating surface of the tubes H_r.

The ratio R : R_r varies between 1 : 0·16 and 1 : 0·60, and is in most cases between 1 : 0·45 and 1 : 0·56. The lowest values, *i. e.* the smallest relative useful grate areas, are given by the Danish State Railway, namely 1 : 0·16 to 1 : 0·23; the Dutch Railway Company comes next, with 1 : 0·3 for its most recent express locomotives, using Belgian coal.

The highest value, *i.e.* the greatest relative useful grate area, namely 2·71 : 1·638 = 1 : 0·6, is to be found on the $^2/_5$ four-cylinder express compound locomotives of the Prussian-Hessian State Railway. The next highest values are found on the Wurtemberg State Railway, namely 1 : 0·56 on express and passenger locomotives, and 1 : 0·54 on goods locomotives.

The ratio of total grate area to total heating surface of smoke tubes R : H_r varies very much with the different locomotives, from 1 : 45 to 1 : 81. On the more recent express and passenger locomotives it is as a rule 1 : 45 to 1 : 65; rather considerably higher maximum values are to be found on the new $^2/_4$ express four-cilynder compound locomotives of the Alsace-Lorraine Railway, namely 1 : 69·5; on the $^3/_5$ passenger four-cylinder compound locomotives of the same railway, namely 1 : 70·8; and on the $^2/_5$ express four-cylinder compound locomotives of the Prussian-Hessian State Railway, namely 1 : 81·6. The latter have R = 2·71 square metres (29·17 square feet), with H_r = 221·18 square metres (2,380·84 square feet), the latter being given by 272 tubes having a diameter of 50/55 millimetres (1 $^{31}/_{32}$ inches/2 $^5/_{32}$ inches) and a length of 5,200 millimetres (17 ft. $^3/_4$ in.) between tube plate.

The largest total grate areas to be found are 4·00 square metres (43·05 square feet) on the most recent express locomotives of the Prussian-Hessian State Railway, 4·07 square metres (43·81 square feet) on the $^4/_5$ goods superheated-steam compound locomotives of the St. Gothard Railway and 4·5 square metres (48·43 square feet) on the $^3/_3$ express superheated-steam compound locomotives of the Baden State Railway.

The lowest ratio is to be found on the Saxon State Railway, with an average of 1 : 45. Most of the administrations vary between 1 : 50 and 1 : 60.

On the goods locomotives, the ratio R : H_r varies between 1 : 50 and 1 : 81, most of the administrations keeping between 1 : 50 and 1 : 65; the higher values are to be found on the $^3/_3$ goods compound locomotives of the Oldenburg State Railway, namely 1 : 69; on the Wurtemberg State Railway, namely 1 : 81; and on the St. Gothard Railway, namely 1 : 70.

Tank locomotives for passenger trains have, on the average, the ralio R : H_r = 1 : 60 to 1 : 65, and goods locomotives 1 : 50 to 1 : 60.

In the case of superheated-steam locomotives with smoke tube superheater, the ratio R : H_r is as a rule 1 : 53 to 1 : 60, if we leave the superheater surface out of consideration, and 1 : 66 to 1 : 70 if we allow for the latter. The ratio of the total grate area to the clear cross-section of the smoke tubes varies between 6·5 and 8·0; the average 7·0 with passenger and express locomotives and 6·5 with goods locomotives on the twin and the compound system.

In the case of superheated-steam, this ratio is about 6·5, allowing for the space occupied in the smoke tubes by the superheater tubes. In addition, the clear cross-section of the smoke tubes is reduced about 15 to 25 per cent by the reduction of the tube diameter at the fire-box tube-plate, and in the case of strongly-contracted smoke tubes, by about 35 to 42 per cent.

The ratio of total direct heating surface, exposed to the fire, to the total heating surface in contact with the water, is about 1 : 1·125 in the case of the wet-steam locomotive.

Drop grates or rocking grates are used on all the locomotives of the Luxemburg Prinz Heinrich Railway, but only a few are in use on other railways. On the more recent locomotives of the Baden State Railway, part of the grate is arranged so that it can drop; this is to facilitate the removal of residues after the fire has been cleaned.

Shaking grates, which are frequent on American railways, are nowhere used, but it would perhaps be advisable to pay more attention to this device in the future, as it enables the locomotive crew to clean the fire on the grate sufficiently for improving the combustion; the operation can be carried out without difficulty even while the train is running; it will make it possible to keep to time even under difficult conditions, particurlarly if coal producing much clinker is used.

8. *Intermediate supports for the barrels and smoke tubes.* — The boilers of the railways we are considering generally have a length of 3,000 to 4,800 millimetres (9 ft. 10 in. to 15 ft. 9 in.) between tube-plates, and do not exceed 5,250 millimetres (17 ft. 2 $^{3}/_{4}$ in.). With boilers of these dimensions, there are no arrangements inside the barrel for supporting purposes. On the other hand, long boilers are in many cases supported externally, generally about the middle, on a saddle-shaped support fixed to the frame plates, on which the boiler is free to slide. The support consists of plate stiffened with angle-iron, or else is a steel casting; it at the same time helps to stiffen the frame transversely. The Baden State Railway and the Prussian-Hessian State Railway have lately introduced spring supports, of the compensating beam type.

The Swedish State Railway, in the case of large barrels, provides two external supports; partly in order to obtain a better distribution of the weight of the boiler over the frame, partly in order to provide against lateral deformation of the frame plates.

In no cases are any very long smoke tubes supported by partitions inside the barrel, and this occurs only incidentally in the case of boilers equipped with Pielock or similar superheaters. The vibration of such long tubes is prevented by a suitable increase in their diameter; for instance barrels from 4,900 to 5,250 millimetres (16 ft. 1 in. to 17 ft. 2 $^{3}/_{4}$ in.) in length have tubes with a diameter of 51/56 millimetres (1 $^{31}/_{32}$ in./2 $^{3}/_{16}$ inches), and this gives sufficient stiffness.

9. *Shape of the front tube-plate.* — Most frequently we find the flanged tube-plate, introduced into the front ring of the barrel and connected with it by riveting. Tube-plates extending to outside the front ring of the barrel are found, in addition to the other kind, on the locomotives of the Dutch State Railway, the Dutch Rail-

way Company, the Luxemburg Prinz Heinrich Railway, the Stockholm-Rimbö Railway, and the Prussian-Hessian State Railway. The connection with the front ring of the barrel is effected by means of an ingotiron angle ring, and by riveting.

10. *Material for the smoke tubes.* — Most of the administrations use exclusively smoke tubes made of the best soft Siemens-Martin ingot iron, and state that these tubes give good results in practice, are to be preferred to the wrought-iron tubes formerly used, are lighter, cheaper, more durable and stronger than tubes of other metal, and are hence also safer.

The Dutch Railway Company uses wrought-iron tubes for their railways and prefers this material to mild steel, as it is less liable to corrosion.

The Luxemburg Prinz Heinrich Railway, the Swedish State Railway and the Stockholm-Rimbö Railway use weldless tubes of mild steel and are satisfied with their life.

The different brasses formerly extensively used for smoke tubes have everywhere been given up, as they are too expensive. On the other hand, copper smoke tubes are in use on the Stockholm-Rimbö Railway, and a few years ago they were also tried on the Swedish State Railway, but in the latter case they did not show a durability corresponding to their price, and are being replaced by steel tubes.

11. *Dimensions of the smoke tubes.* — The length of the smoke tubes between tube-plates varies between 3,000 and 5,250 millimetres (9 ft. 10 in. and 17 ft. 2 $^{3}/_{4}$ in.); on most of the locomotives the length is between 3,600 and 4,800 millimetres (11 ft. 9 $^{3}/_{4}$ in. and 15 ft. 9 in.). In order that the tubes may have the stiffness necessary, their diameters are increased with the length.

The thickness of the tubes varies between 2 and 2·75 millimetres (between $^{5}/_{64}$ and $^{7}/_{64}$ inch); it is 2·5 millimetres ($^{3}/_{32}$ inch) on most of the railways.

The diameter of the tubes is reduced at their fire-box ends; the contraction adopted by many administrations varies between 3 and 8 millimetres (between $^{1}/_{8}$ and $^{5}/_{16}$ inch), while some go as far as 11 millimetres ($^{7}/_{16}$ inch), in order to have greater strength in the interspaces of the fire-box tube-plate. This considerable contraction in the clear cross-section of the tubes available for the passage of the hot gases has not had a bad effect on the action of the draft; the Alsace-Lorraine Railway, the Bavarian State Railway and the Danish State Railway confirm this. The last railway contracts the clear cross-section of the smoke tubes of the most recent locomotives from 45·5 to 34·5 millimetres (1 $^{51}/_{64}$ to 1 $^{23}/_{64}$ inches), that is to say by 11 millimetres ($^{7}/_{16}$ inch) and accordingly reduces the clear cross-section by 42·5 per cent, while this reduction is only 15 to 35 per cent elsewhere. On the Swedish State Railway, it is 15 per cent.

At the smoke-box ends, all the administrations uniformly expand the diameter of the tubes by 2 to 3 millimetres ($^{5}/_{64}$ to $^{1}/_{8}$ inch).

In some long boilers, some of the tubes are used as stay tubes, and these generally have a diameter of 34 to 36 millimetres (1 $^{11}/_{32}$ to 1 $^{13}/_{32}$ inches) inside and 50 to 52 millimetres (1 $^{31}/_{32}$ to 2 $^{1}/_{32}$ inches) outside.

The larger smoke tubes used for superheating purposes have an external dia-

meter of 119 to 133 millimetres (4 21/32 to 5 1/4 inches), and are all 4 to 4·5 millimetres (5/32 to 11/64 inch) thick. At the smoke-box ends, they are enlarged by about 3 to 4 millimetres (1/8 to 5/32 inch), and at the fire-box ends they are contracted by about 18 to 20 millimetres (23/32 to 25/32 inch). The superheating tubes proper have an external diameter varying between 32 and 38 millimetres (between 1 1/4 and 1 1/2 inches) and are 3 to 4 millimetres (1/8 to 5/32 inch) thick.

12. *Fixing the tubes in the tube-plates.* — The tubes are in the first place driven into the tube-plates so that the shoulder of the tube takes tight against the inside of the back tube-plate and then expanded by a roller expander of the ordinary type with three small rollers placed slightly conically; both ends are expanded simultaneously. The number of rollers is increased in the case of tubes of larger diameter. The Swiss Federal Railway uses for the copper ends at the fire-box, roller expanders of special type, with seven to eleven small rollers. The expanding is to be effected with as uniform a pressure, which must not be excessive, as possible, in order to avoid any deformation of the tube holes and any lateral or vertical movement of the metal forming the walls of the holes. The holes in the fire-box tube-plate are generally coned to a taper of about 1 : 40, contracting towards the front.

The fire-box ends of the tubes which generally project 8 to 10 millimetres (5/16 to 13/32 inch) (with some administrations only 6 millimetres [1/4 inch]) are then beaded over; either a special beading tool is used by hand, or else they are bent out by hammering with a ball hammer and then beaded by using a pneumatic hammer and a special beading tool. On the Swedish State Railway, the back ends of the smoke tubes, as far as they go into the tube-plate, are tinned outside and rolled in with a taper of 1 : 30. The St. Gothard Railway has copper ends brazed on to its tubes at the fire-box ends; these are expanded into the fire-box tube-plate and fitted with a ferrule which is beaded over so as to extend beyond the bead of the copper.

The tube ends at the front tube-plate project about 5 millimetres (13/64 inch); they are fixed by expanding, but are not beaded over. They are however expanded by driving in a drift having a considerable taper.

The expansion at the front end is in every case effected by the usual method.

13. *Serve tubes.* — Serve tubes are used with success on the Alsace-Lorraine Railway. The results obtained there have all been favourable, provided that the tubes have been kept properly clean. An effective method of proper cleaning consists in blowing steam through the tubes and then drawing wire brushes through, the locomotives at the time being in steam. The Dutch State Railway has also obtained good results with Serve tubes. The two administrations are accordingly satisfied with the advantages obtained with these tubes as regards good steam production, durability and strength, as compared with their higher initial cost and the somewhat higher cost of maintenance.

Less favourable results have been obtained with Serve tubes on the Baden, Prussian and Wurtemberg State railways, and on the Swiss Federal Railway. These

administrations draw attention to the fact that a hard crust of soot forms on the ribbed inner surface of these tubes in a short time, which cannot be properly removed owing to the comparative inaccessibility of the inside of the tubes to the cleaning appliances, so that the initially-favourable results, as regards steam production, and the saving of coal, at first amounting to several per cent, are soon lost again; in consequence of the difficult cleaning operations, which have frequently to be repeated, and the small durability of the joints, the cost of upkeep is materially greater than in the case of locomotives with smooth tubes. They also draw attention to the fact that it takes longer to repair the locomotives, and that it is more difficult to utilize them properly; and taking into consideration that the Serve tubes cost considerably more, they present no advantage as compared with smooth tubes. These administrations have accordingly decided against the further use of Serve tubes and have considered it necessary, both from the technical as well as from the economical point of view, to replace the existing Serve tubes by smooth tubes.

14. *Corrosion of smoke tubes.* — *a*) Corrosion of iron and steel smoke tubes has as a rule only been observed in a few districts with bad feed water, and has taken the form of pitting and grooving; it is generally most strongly developed near the fire-box tube-plate and up to a distance of 300 millimetres (11 $^{13}/_{16}$ inches) from it. It seems that the chemical and electrolytic reactions between the two metals iron and copper and the weakly-acid solutions in the water are most active under the influence of the high temperature. New tubes, which had only been three to five months in the boiler, were strongly attacked and damaged inside this zone while no traces of corrosion were to be found anywhere else. Only slight corrosion takes place if the water is of good quality. The tubes made of mild steel seem to be attacked more readily than those made of ingot iron.

b) Copper tubes have shown no particular corrosion, nor have cracks been observed. Brass tubes are not used.

c) The best means, besides frequent washing, for preventing the extensive corrosion of tubes if the water contains acids or salts and substances which form scale, is the careful purification of the feed water before it is used; this is generally recommended and is stated to give good results. Experiments with soda and other chemicals placed in the boiler did not result in reducing the corrosion.

Galvanized steel or iron smoke tubes have not been tried anywhere, but the Prussian, Bavarian and Wurtemberg State Railway have lately been trying smoke tubes made of special acid-resisting ingot iron, which are supplied by the Mannesmann works of Düsseldorf, and are made acid-resisting by a process carried out by the firm Krupp of Essen. The Dutch Railway Company uses wrought-iron tubes made by a special process (which is not described), which is intented to prevent corrosion.

d) Copper sleeves to the iron or steel smoke tubes, at the fire-box ends, are not used on the Alsace-Lorraine Railway, the Dutch Railway Company, the Luxemburg Prinz Heinrich Railway, the Saxon State Railway, the Oldenburg State Railway, the Prussian State Railway, the Dutch State Railway, and the Swedish State Rail-

way. The Danish State Railway pronounces them to be costly and unnecessary; on the other hand, the Bavarian State Railway, the Wurtemberg State Railway, the Swiss Federal Railway, the St. Gothard Railway, the Rhetian Railway and the Stockholm-Rimbö Railway prefer copper sleeves and state that they give good results both as regards tightness and durability of the joints and reduced corrosion.

The Baden State Railway considers copper sleeves satisfactory in every respect when pressures are low, but finds that with higher pressures they do not give enough resistance to deformation. The administration has accordingly adopted tubes made wholly of iron for boilers working at pressures greater than about 12 atmospheres; in the case of boilers working at a pressure of 16 atmospheres, a thin copper ring is brazed on the outside at the point where the tube is in the tube-plate, so as to obtain a copper-to-copper joint.

The Wurtemberg State Railway attributes the cracks occasionally found in the copper ends immediately next the tube-plate to bad quality of the copper, or to molecular changes in its structure; they praise the tightness of the joints in the tube-plate, as long as the beads are not burnt away, and in that case they restore the tightness by driving in steel rings.

The Swiss Federal Railway has not observed any real cracks in the copper sleeves, but has observed grooves inside the tubes, produced by the scoring of the cinders. Hence, as an experiment, the iron tube has been contracted at the back end and a copper ring has been brazed on to the iron tube. Iron tubes without copper sleeves were also in use for a considerable time; but bad results were obtained as it frequently became necessary to expand the ends again and this damaged the inter-spaces of the tube-plates. It has been found that copper sleeves keep tight better.

The St. Gothard Railway also speaks in favour of copper sleeves, as tightness is maintained, and so does the Rhetian Railway, which was unable to keep the joints tight when iron tubes without copper sleeves were used.

The Swedish State Railway formerly used steel tubes with copper sleeves. They certainly kept tight better than all-steel tubes, but were less durable in consequence of the great wear which was produced at the back end of the tube by the hot gases passing through; hence they are no longer in use now.

The copper sleeves generally have a length of 100 millimetres ($3\ ^{15}/_{16}$ inches), but are also made up to 220 millimetres $8\ ^{11}/_{16}$ inches) in length. They are turned to a taper over a length of about 35 to 40 millimetres ($1\ ^{3}/_{8}$ to $1\ ^{9}/_{16}$ inches); a corresponding taper hole is reamed in the end of the iron tube, and the two are brazed together. This system of joining them is generally described as durable and as giving good results.

15. *Ferrules.* — Ferrules and liners are used regularly only by a few administrations. The Wurtemberg State Railway uses them in order to ensure the tightness of the tubes, and in the case of new tubes at those parts in the tube-plates which are most exposed to thin flames, in order to prevent the beads of the copper ends from being burnt off.

The Danish State Railway, in the case of fire-boxes made of hard or special

copper, use copper liners having a taper of 1 : 40 between the iron tube and the tube-plate in order to ensure a tighter joint. The ends at the fire-box are not beaded in this case; trials were made in which beaded ends gave no better results than unbeaded ends.

The Swiss Federal Railway uses ferrules 1·5 millimetres ($^1/_{16}$ inch) thick having a taper of 1 : 40 in order to protect the copper tube ends which have a flat flange.

The St. Gothard Railway has obtained good results with ferrules for protecting the ends of the copper sleeves against internal scoring and the copper bead from being burnt away by thin flames.

The Rhetian Railway uses ferrules 40 millimetres ($1\ ^9/_{16}$ inches) long and having a taper of 1 : 40 in order to make the copper sleeves tighter and protect them against being burnt away.

All the other administrations dispense with ferrules and only use them exceptionally as a makeshift in the case of leaky tubes, when the ordinary method of expansion no longer works. The introduction of arches made of fire-brick, now general, has much reduced the risk of burning away the beads and tube ends, and leads these administrations to consider ferrules unnecessary; moreover, the clear cross-section of tube available for the hot gases is not reduced.

16. *Arrangement of the tubes in the tube-plate.* — All the administrations arrange the tubes in vertical rows, as the steam bubbles can rise more freely, the water can circulate better, there is greater accessibility when washing out and cleaning the boiler and when removing scale, and less scale in deposited, than when the tubes are arranged in horizontal rows.

The distance between the tubes, centre to centre, varies with the diameter of the tubes. With diameters of 40 to 45 millimetres ($1\ ^9/_{16}$ to $1\ ^{25}/_{32}$ inches), the distance is 60 to 63 millimetres ($2\ ^3/_8$ to $2\ ^1/_2$ inches); with diameters of 45 to 50 milimetres ($1\ ^{25}/_{32}$ to $1\ ^{31}/_{32}$ inches) it is 65 to 68 ($2\ ^9/_{16}$ to $2\ ^{11}/_{16}$ inches) and even 70 millimetres ($2\ ^3/_4$ inches); this corresponds to interspaces of 15 to 20 millimetres ($^{19}/_{32}$ to $^{25}/_{32}$ inch), measured outside the tubes.

In newer designs, the number of tubes is reduced and at the upper corners the distances are increased to 75 millimetres ($2\ ^{31}/_{32}$ inches) and more, so as to obtain stronger interspaces in the tube-plate and prevent cracks from forming there. They are also placed further away from the bend, in order to prevent any damage which may occur there.

17. *Pressure of the steam.* — The German, Danish, Swedish and Swiss railways have all increased the working pressures of the boilers of their more recent express and passenger locomotives to beyond 12·65 kilograms per square centimetre (180 lb. per square inch) and their new superheated-steam compound locomotives all work at pressures of 13 to 16 kilograms per square centimetre (185 to 228 lb. per square inch). It has not been necessary to take any special measures for keeping the tubes tight or for the proper maintenance of the fire-box, beyond generally strengthening the boiler and reducing the distances between the stay-bolts in order to prevent the fracture of the stays and the deformation of the fire-box walls. Some of the administrations, in order to stiffen the tube-plates in the case

of boilers working at high pressures, use thick stay tubes screwed into the tube-plates ; about five of these stay-tubes, distributed uniformly among the other tubes, are used, having an external diameter of 50 to 52 millimetres (1 $^{31}/_{32}$ to 2 $^{3}/_{64}$ inches) and an internal diameter of 32 to 34 millimetres (1 $^{17}/_{64}$ to 1 $^{11}/_{32}$ inches). Attention is drawn to the fact that everything depends on the proper treatment of the fire and of the feed-water gear.

On goods locomotives and tank locomotives, the pressure is nearly always 10 to 12 kilograms per square centimetre (142 to 171 lb. per square inch), and this is only seldom exceeded, for instance on the goods locomotives of the St. Gothard Railway which work at up to 15 kilograms per square centimetre (213 lb. per square inch).

The St. Gothard Railway draws attention to the fact that with pressures of 15 kilograms per square centimetre (213 lb. per square inch) and upwards, the use of ferrules has also proved satisfactory for keeping the tubes tight.

The Prussian-Hessian State Railway, in the case of their $^{2}/_{5}$ four-cylinder express compound locomotives, working at pressures of 14 to 16 kilograms per square centimetre (199 to 228 lb. per square inch), had to renew the fire-box tube-plates at an early date owing to cracks in the tubes, and the smoke tubes also frequently showed leaks; but the experience gained up till now, shows that this is not to be attributed to the high pressures so much as to the design of these locomotives, which have wide fire-boxes extending beyond the frame plates. Here again special care is taken with the firing and with the washing out of the boiler in order to reduce the damage to which the tubes and the fire-box are more liable when the pressures are high.

The Dutch State Railway, the Dutch Railway Company, the Luxemburg Prinz Heinrich Railway and the Stockholm-Rimbö Railway only have boiler pressures which do not exceed 12·65 kilograms per square centimetre (180 lb. per square inch).

The introduction of superheated steam checked the tendency to use high boiler pressures; the pressure adopted for express and passenger locomotives was as a rule 12 kilograms per square centimetre (171 lb. per square inch), and below 12·65 kilograms per square centimetre (180 lb. per square inch) in the case of twin engines. More recently however, the Saxon State Railway, the Bavarian State Railway, the Baden State Railway, the Wurtemberg State Railway, the Swiss Federal Railway and the St. Gothard Railway have again been constructing superheated steam compound locomotives with higher boiler pressures; for instance 16 kilograms per square centimetre (228 lb. per square inch) on the Bavarian $^{3}/_{5}$ express four-cylinder locomotives with superheater.

18. *Spacing of the tubes and stays. Hammering the copper of the fire-box tube-plate.* — The spacings given under questions 16 are looked upon as satisfactory; but with the newer boilers, in order to prevent the fractures which often occur in the interspaces of the upper corners of the tube-plate, one does not go so near the bends, and the spaces between the tubes are made larger at the upper corners of the fire-box tube-plate, as may be required, slightly reducing the number of

the tubes. The total heating surface of the tubes is thereby reduced by about 4 per cent.

The spaces left between the stays have been materially reduced in the newer locomotives, if only on account of the increased boiler pressure; the distance, centre to centre has been reduced to about 90 millimetres (3 $^{9}/_{16}$ inches), and some administrations have reduced it to 85 to 80 millimetres (3 $^{11}/_{32}$ to 3 $^{5}/_{32}$ inches), the shank of the bolt having a diameter of 19 to 22 millimetres ($^{3}/_{4}$ to $^{7}/_{8}$ inch).

The process of hammering the copper tube-plates in order to harden them is carried out on the Alsace-Lorraine Railway. the Danish State Railway, the Dutch Railway Company, the St. Gothard Railway and the Rhetian Railway. On the Swiss Federal Railway, some of the tube-plates are hardened by hammering; with others, the tube holes are drifted open in order to compress the metal; but no special advantages has been observed.

19. *Extended smoke-boxes. Prevention of sparks.* — Extended smoke-boxes are used on the newer locomotives of most of the railways and are up to 2·7 metres (8 ft. 10 $^{5}/_{16}$ in.) in length. The exceptions are the Saxon State Railway, the Wurtemberg State Railway, the Stockholm-Rimbö Railway, the St. Gothard Railway and the Rhetian Railway. The advantages which are recognised are that a more uniform vacuum can be kept up in the extended smoke-boxes and that there is more room for cinders, without the capacity of the smoke-box becoming too much reduced. It is also easier to find room for other appliances (connecting tubes, superheater, spark arrester, etc.); fewer sparks are ejected and the more uniform draft results in a saving of fuel.

Spark arresters of various kinds are used for preventing the ejection of the sparks from the chimneys. They consist of flat screens made of sheet metal (with long or circular holes) or made of wire netting (one or two or three rows of round or angular wire placed over each other); or else are funnel-shaped, filling the space between the blast pipe and the chimney, and made of flat bar, angle iron, wire work, or loose wire loops connected together like chain mail. Locomotives which are fired with lignite or peat have, besides these spark arresters, also spark catchers of onion or other shape placed on the chimney so as to catch any sparks which may have passed through the spark arrester.

The utility of the devices and their effect on reducing the power of the sparks to set fire to any thing depend chiefly on the nature of the coal, and its behaviour when being burnt under the conditions of draft normally obtaining on the locomotives in question, and accordingly the clear spaces in the screens, etc., also vary extensively; we find used long openings measuring 50 × 6 millimetres (1 $^{31}/_{32}$ in. × $^{1}/_{4}$ inch), round openings having diameters of 8 and 10 millimetres ($^{5}/_{16}$ and $^{13}/_{32}$ inch), galvanized wire netting made of wire 2·5 millimetres ($^{3}/_{32}$ inch) in diameter, with a mesh of 6 millimetres ($^{1}/_{4}$ inch), and others.

As a rule, these spark arresters reduce the ejection of sparks, the larger red-hot cinders being kept back in the smoke-box or broken up; but they do not make it possible altogether to stop the emission of the sparks, which is sometimes attended

with very costly consequences. The administration of the Prussian State Railway has on various occasions had to pay compensations varying in amount from 30,000 to 50,000 marks (£1,500 to £2,500); in some cases it exceeded 100,000 marks (£5,000) and in one case it even exceeded 1,500,000 marks (£75,000). The great heat and the variations in the temperature soon produce warping effects, and together with the comparative weakness of the parts, only make it too easy for a larger opening to form. Special attention must therefore be devoted to the proper inspection of these appliances while in use, and to their proper construction and adjustment at the workshops. Moreover, there is not one of these devices which is absolutely certain not to become blocked, at all events partly, particularly if the tubes are not quite tight and the ash becomes damp; they then interfere with the proper draft.

The Swiss Federal Railway has accordingly given up the use of special spark arresters of this kind on its newer locomotives, and has placed deflector plates in the smoke-box instead; these as a rule give good results and interfere less with the draft. The Danish State Railway also uses deflector plates. Deflector plates are largely used in America and these give very good results, as the author has had opportunity to observe; it would be well worth making a more extended trial of them in Europe.

There is nothing new, as regards the joint of the smoke-box door, which must be made perfectly air-tight in order to prevent internal combustion and consequent warping; but it may be mentioned that on many of the more recent locomotives the smoke-box is given a coned shape (taper 1 : 2 to 1 : 1·5) in order to reduce the resistance of the air in front.

20. *Steam dome.* — The most recent locomotives of all the administrations have one steam dome, in a number of cases also two steam domes which are connected together. Many of the administrations fit the inside of the dome with special deflector plates and screen plates or hoods and screens for separating the water; moreover, on some of the locomotives, for instance goods locomotives of the Saxon State Railway, special collectors situated along and above the boiler have been fitted. The Bavarian State Railway have for some time been making experiments with steam driers and water separators of different kinds.

The locomotives of the Oldenburg State Railway formerly did not have steam domes at all; now they are also fitted with such domes.

21. *Boiler lagging.* — Different kinds of asbestos are used for lagging; the asbestos is sewn together so as to form cloth about 25 millimetres (1 inch) thick. This is placed either direct on the boiler plate, or fixed under the sheet-iron cover, which is about 2 millimetres ($^5/_{64}$ inch) thick, by means of hoop iron; in some cases, it is also fixed to special iron rings which are permanently connected with the sheet-iron cover. Some of the railways only apply blue-asbestos lagging to that part of the boiler which projects into the cab, so as to protect the locomotive crews against the radiant heat. The Wurtemberg State Railway, the Dutch State Railway, and the Dutch Railway Company use impregnated felt, while other administrations complain that this material readily

becomes destroyed. Wood lagging has also been tried, but is unsatisfactory because it has a short life and does not give sufficient protection against the heat.

The results generally obtained show that there is a reduction in the radiation and consequently a sufficient reduction of the temperature in the cab, but no measurements of a more accurate kind have been made.

22. *Systems of thermal storage.* — No system of thermal storage in the boilers is used.

23. *Mechanical stoking.* — The Baden State Railway has quite recently been using locomotives with extra firing by means of petroleum residues, in order to reduce the amount of smoke in sections where there are many tunnels. The arrangement is the same as that used on the Arlberg lines of the Austrian State Railway.

On two small tank locomotives of the Bavarian State Railway, which are run each by one single man, the coal space is arranged so as to form a charging cone, which is above the back wall of the boiler.

This arrangement has given good results, but is only suitable for simple traffic conditions.

The Swedish State Railway made some trials with mechanical stokers on locomotives which burnt peat, but no useful results were obtained. No other trials are reported.

As a summary of all this information, I will read the following conclusions, given in my report :

Belpaire boilers are used occasionally, boilers with superelevated fire-box roof only exceptionally. The design preferred is that in which the barrel extends into the fire-box, the fire-box shell just having the same diameter as the last ring of the boiler. Cylindrical fire-boxes, in so far as they have been tried, have not given satisfactory results, and special combustion chambers have not been used. Wide fire boxes, extending beyond the frame plates, are still in the experimental stage.

Radial roof stays have given satisfactory results and they, as well as stays arranged vertically, are often used. Roof bars as the sole means of stiffening the top of the fire-boxes are no longer to be found on the more recent locomotives. Short roof bars instead of the two or three front rows of roof stays are nearly always used, specially arranged so as to allow for the mobility of the front top part of the fire-box.

The most suitable material for fire-boxes is generally recognized to be copper, obtained either by smelting or electrolytically. Special alloys, for instance nickel copper, are being tried. Ingot-iron fire-boxes have as yet given unsatisfactory results.

Fire-doors are generally in the form of single swing doors, less frequently in that of sliding doors in two parts. In the case of wide boilers, double swing doors have been introduced, and also drop doors in three parts, opening inwards. Devices for an over-grate supply of air are generally provided and in many cases developed into real smoke-consuming appliances.

The joints at the fire-hole are generally made with rings of rectangular section, the thickness of which has lately been materially reduced; Webb's dished joint is also used. Both designs have given good results. Simple riveting suffices in both cases.

The ratio of total grate area to useful grate area, $R : R_f$, shows that the latter is being increased, as the former average of 1 : 0·45 is in many cases exceeded.

The ratio of total grate area to total heating surface, $R : H_r$, is also altered in favour of the latter and illustrates the tendency to utilize the quantity of heat produced on the grate,

in so far as it is still possible to do so profitably in practice.

Movable grates have as yet had comparatively little attention devoted to them. In so far as they are used, this is to facilitate the cleaning of the fires after the locomotive has been used. Cleaning the grates while running is less frequently the object aimed at, but it might be advisable to pay greater attention to this in the future in the case of locomotives which have to do heavy and long runs.

Ingot iron is generally pronounced to be the most suitable material for smoke tubes; in a few cases mild steel is named. Copper is only used exceptionally for this purpose, and brass not at all.

Serve tubes are generally condemned; the Alsace-Lorraine Railway forms the sole exception.

The careful purification of the feedwater *before* it is put into the boiler is the chief means recommended for preventing the production of defects in the smoke tubes and tube-plates.

Copper sleeves to the smoke tubes at the fire-box ends are not approved by the majority of the administrations; only the south German and Swiss railways consider them useful and state that good results are obtained.

Ferrules are only considered of practical value in a few cases, especially when copper sleeves are used. The system of placing copper liners round the outside of the tube ends, or of brazing them on, seems to give good results.

Several administrations have found the cold hammering of the copper plates used for the fire-boxes to give good results.

Extended smoke-boxes are much used and are considered advantageous.

Steam domes are used everywhere.

Blue asbestos and white asbestos are preferred for lagging and are found to give good results.

Mechanical stoking is not used in the case of any of the larger boilers.

Firing with liquid fuel (naphta, tar) is being tried experimentally; it is advisable to investigate this point more closely wherever such fuel can be obtained at a moderate price.

Working pressures exceeding 12·65 kilograms per square centimetre (180 lb. per square inch) are used nearly everywhere, on express and passenger saturated-steam locomotives; on goods locomotives, the working pressure seldom exceeds 12 kilograms per square centimetre (171 lb. per square inch). Superheated-steam twin locomotives work at pressures of 12 kilograms per square centimetre (171 lb. per square inch); superheated-steam compound locomotives work at pressures of from 13 to 16 kilograms per square centimetre (185 to 228 lb. per square inch).

The President. (In French.) — I request the reporters whom we still have to hear, to be as concise as possible. I call upon Mr. Antochine, reporter for Russia.

Mr. Antochine, *reporter.* (In French.) — Gentlemen, I will limit myself to drawing your attention to a few points only of my report.

The boilers of the Russian locomotives can be divided into three distinct groups. The first, which includes the old boilers mostly built abroad, is not considered in my report. The second group includes the boilers of passenger and goods locomotives of the type which we call the standard type; these boilers were all built in Russia on very nearly the same plan, there being only two variants. The third group includes the most recent locomotives used for hauling passenger trains, and on some lines also for hauling goods trains. My report accordingly deals with the two latter groups.

As regards the details about the locomotives, I have arranged them in accord-

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ance with the very complete list of questions drawn up by my colleagues Messrs. Archbutt and Fowler.

A detailed list of questions was sent to thirty State railways and privately-owned railways. Twenty-one sent answers, a summary of which is given in my report.

In most of the boilers of the two latter groups, the fire-box is of the Belpaire or of the round-topped type, always stiffened by vertical stays. The radial stays found in the boilers of some American locomotives have been replaced by vertical stays. We do not find any cross stays in the boilers of the two latter groups.

Cylindrical fire-boxes are not used in Russia.

Fire-boxes of iron (side walls) are extensively used on the Vladicaucasus line (out of 809 locomotives, 302 are so equipped); up to the present the results have been good, but the use of hard water results in corrosion of the iron plates.

Eight other administrations are using, as an experiment, iron for the fire-boxes partly in the form of full sheets, partly for tube-plates and back plates. The results of these experiments vary, that is to say, that they are good on lines where the water has not more than 20 degrees (24·7 English degrees) of hardness and bad where the water has from 20 to 90 degrees (24·7 to 111 English degrees) of hardness. The iron plates require more looking after than the copper plates, owing to leaks at the smoke tubes. In order to prevent such leaks, two administrations are trying the interposition of thin liners of copper (1 to 1·5 millimetres [$^3/_{64}$ to $^1/_{16}$ inch] thick), placed between the tube-plate and the smoke tube; up till now no definite results have been obtained.

Most of the fire-holes are of two shapes: either round, or rectangular with the corners rounded. Many railways prefer a hole without special frame (the Webb joint); others prefer a hole with a ring having a width not exceeding 50 millimetres ($1\ ^{31}/_{32}$ inches). The latter shape makes it easier to scrape the scale from the surfaces.

The smoke tubes are made of ingot iron exclusively.

This material, which is much cheaper than brass, works very well, requires no special maintenance, and as regards conductivity, is practically equivalent to brass.

The Russian railways use several classes of fuel: petroleum residues, crude petroleum, coal, anthracite, lignite and wood.

Petroleum residues and crude petroleum make a grate unnecessary, and this is replaced by bricks arranged in different ways with different air spaces in between. The size of these air spaces varies, in the different systems between 0·3 to 0·15 of the original grate area. The tube area remains the same.

In locomotives fired with coal or with wood, the useful grate area as compared with the total grate area varies with the nature of the fuel and its quality, from 57 to 26 per cent; the higher figures refer to wood and lignite.

The ratio of the total tube area to the useful grate area varies between 0·22 to 0·08.

Rocking or drop grates are only used on the Perm line, which uses coal containing 8 to 12 per cent of ash and 4 to 6 per cent of sulphur.

This railway considers that rocking grates are convenient and useful and effect a saving in fuel of from 3 to 5 per cent.

The smoke tubes of the boilers of the most recent locomotives have as a rule an external diameter of 51 millimetres (2 inches), but sometimes also one of 45 millimetres (1 13/16 inches); at the fire-box ends they are contracted to 45 millimetres, 40 millimetres internal diameter (1 13/16 and 1 9/16 inches) and at the smoke-box ends they are enlarged to 53 and 47 millimetres (2 3/32 and 1 27/32 inches) respectively. The thickness of the tubes is nearly always 2·5 millimetres (7/64 inch) and only rarely 3 millimetres (1/8 inch). Near the fire-box the tubes often have copper ends joined on, which have a thickness of 3 millimetres (1/8 inch), sometimes of 4 millimetres (5/32 inch), and very rarely of 5 millimetres (3/16 inch); no such ends are put on at the smoke-box ends.

Sometimes, but rarely, ferrules are used inside the tubes. Ferrules are sometimes used at the fire-box ends, in order to keep the joint between the tube and the plate tight, or in order to protect the ends of the tubes from being burnt.

Pressures higher than 180 pounds per square inch, and up to 206 pounds per square inch, are only used on the Vladicaucasus (the Orient and China) and the Riazan-Ural lines. The first of these railways states, that it is wholly satisfied with the use of this pressure and has found no difficulty; the second has eight locomotives working at the pressure; it is observed that stays break frequently, but there is no trouble as regards the tightness of the tubes and the behaviour of the tube-plate; the Riazan-Ural line has been using these locomotives for the last two years and the Vladicaucasus line for about eight years.

I now come to the conclusions of my report which are as follows :

The present well-marked tendency on Russian railways, as far as locomotive boilers are concerned, is :

1° To generalize (standardize) both as regards design and as regards dimensions;

2° To strengthen the crown by means of Belpaire stays;

3° To stay the shell of the fire-box without using roof bars;

4° To substitute mild steel for copper in the case of fire-boxes, although most of the lines still use copper;

5° To use only mild steel for smoke tubes. These are cylindrical without ribs inside or outside;

6° The absence of heat storage on the most recent types of boilers.

Mr. Nadal, *reporter for France, Belgium, Italy, Spain and Portugal.* (In French.) — It is a commonplace to say that the boiler is one of the chief preoccupations both of the engineer who designs the locomotive as well as of the engineer who uses this locomotive for hauling trains. Leaving out of consideration certain types of boilers which are still in the experimental stage (water-tube boilers), we may say that since 1830, since George Stephenson's *Rocket*, the general shape of locomotives has not changed; but their dimensions have been greatly increased.

The fire-boxes are either rectangular (Belpaire type) or round-topped. The latter type is more usual; the fire-box and the barrel are joined in a rational way. The former is preferred in France in recent designs. Last year, when I had to design a *Pacific* locomotive with a large fire-box, I was at first in favour of having a round-topped fire-box of what is known

as the wagon-topped type. It was found that this type of fire-box led to an increase in the load at the back (this is particularly objectionable in a *Pacific* locomotive of which the carrying axle must not be overloaded) of more than 1,000 kilograms (2,200 lb.), as compared with a Belpaire fire-box of equal power; this led to the adoption of the Belpaire type.

The fire-box crown is always secured by means of stays, although this system is more expensive than the old system of bars; but stays give a better connexion between the crown of the fire-box and the outer shell and are less in the way. Several railway administrations have tried steel fire-boxes, it seems without success.

In the large fire-boxes of modern locomotives, rocking grates are being used more and more; they make it easy to clean the fire.

The tubes are generally made of steel; brass is only used when the water is of bad quality. The usual dimensions of smooth tubes are : outside diameter, 50 millimetres (1 $^{31}/_{32}$ inches); thickness 2·5 millimetres ($^{7}/_{64}$ inch). There is a tendency to increase this diameter; in the case of recent *Pacific* locomotives it is increased to 55 or 57 millimetres (to 2 $^{5}/_{32}$ or 2 $^{1}/_{4}$ inches) and the length of the tubes attains about 6 metres (19 ft. 8 in.). The tubes are drifted, then as a rule beaded over, at least at the fire-box tube-plate, and no ferrules are used.

Serve tubes continue to be used extensively in France, but only when the length does not exceed 4·50 metres (14 ft. 9 in.). The objection is raised that they are too rigid, and that this affects the fire-box tube-plate.

The high pressures of 15 to 16 atmospheres (213 to 227·5 lb. per square inch), which have become general during the last fifteen years, like the use of four-cylinder compounds, remain in favour. There is no doubt that high-pressure fire-boxes have a shorter life than the older fire-boxes the pressure in which did not exceed 12 atmospheres (170·6 lb. per square inch). It seems, however, that there is an improvement in this respect as we gain greater knowledge of the effects produced by higher pressures, and fire-boxes are consequently better looked after. It still has to be ascertained whether the life of wide fire-boxes, approximating to a cubical shape, will not be better than that of long and narrow fire-boxes.

Moreover, if superheating becomes general, it will probably be possible to return to more moderate pressures.

The damage which is produced in fire-boxes, particularly in the tube-plate, requires much attention from locomotive engineers. Such damage is attributed to numerous causes, but little is known of their relative importance. Are there any to which the results are chiefly due? I would answer this in the affirmative; I think that the effects of expansion and contraction, due to the successive heating and cooling of the boiler, are the chief causes of damage in the fire-box. These phenomena gradually lead to the destruction of the joints; they are, moreover, inevitable.

The conclusion to be drawn from this theory is firstly that attempts must be made to improve the shape so as to make the effects of expansion more uniform; secondly, as soon as any damage appears, it should be repaired at once, without waiting for it to extend, in which case it

may become irreparable. For instance, as soon as tubes begin to leak, they should be replaced wholly or partly, instead of proceeding to repeated expanding which has a very deleterious influence on the tube-plate.

Moreover, repairs made at once prove to be cheapest in the long run.

In order to give boilers a good life, it is hence recommended :

1° *As regards construction :*

To give the curves of the plates as large radii as possible;

To facilitate expansion, which cannot be resisted;

To strengthen the parts liable to crack, for instance the interspaces between the tubes in the upper corners of the tube-plate;

To increase the width of the water spaces as much as possible;

To bead over the tubes at the fire-box tube-plate;

To use stays made of a metal which resists heat better than copper, for instance manganese bronze.

2° *As regards current use :*

To avoid sudden cooling while running, by looking properly after the fire and the supply of water; more especially cold water should not be injected in quantity when the fire is not sufficiently brisk;

Not to cool the boiler suddenly at the end of the journey;

Not to start washing it out till after it has become well cooled;

To use water of good quality.

Mr. Fowler, *reporter for Great Britain.* — The most important change during recent years is the greatly extended use of the Belpaire fire-boxes. Boilers fitted with such fire-boxes apparently produce steam more readily than those with round topped fire-boxes, and offer better facilities for cleaning the top of the fire-box. For this reason a certain number of administrations, who still use round topped fire-boxes, make use of radial stays.

Cylindrical fire-boxes have been tried, but without success because of the difficulty in raising steam.

Copper is still the most frequently used metal for internal fire-boxes. Several companies who have tried steel for this work have discontinued its use because of trouble from corroding and cracking.

Steam pressures generally have been considerably increased, but some administrations, who have tried pressures greater than 200 lb. per square inch, state that the employment of such high pressures involve a large expenditure for maintenance.

The use of steel tubes has considerably extended. In the majority of cases the reduction in the first cost resulting from the employment of this material largely compensates for the increased cost of upkeep.

Considerable importance is attached to the question of the spacing of smoke tubes, and the method of fixing them into the tubeplate in order to prevent leakage of the tubes and cracking of the tube plate between the tubes.

Superheating has been tried, but the use of this method is as yet not very extended.

Automatic stoking has also been tried without success.

Considerable attention has been given

to the question of the admittance of air into the fire-box with a view to improving the combustion. A standard type of fire-box door has not yet been arrived at.

Mr. Papp, *reporter*. (In German.) — My report should have covered Austria, Hungary, Rumania, Bulgaria, Servia and Turkey; but unfortunately very few administrations sent answers to the list of questions, no doubt because they had hardly anything new to mention on the subject of the improvement of locomotive boilers.

1. *Types of boiler*. — As has already been stated, innovations in the types of boilers are as a rule rare. The only thing to be mentioned is the boiler of the Brotan type, with water-tube fire-box, but the trials made with them have not yet been completed. The results so far obtained are favourable; the boiler can do considerably more work and the small damage which has occurred at a few tubes is so far not of importance.

2. *Stiffening the fire-box crown*. — The stiffening of the fire-box crown is effected generally by means of stay-bolts which, apart from a few exceptions, are not radial to the top of the boiler, but vertical to the fire-box crown. The front parts of the fire-box crown as far back as the two front rows of stay-bolts, are often fitted with strap bars, in order to provide for the expansion of the tube-plate.

Quite recently, fire-boxes of the Polonceau type are again being used more extensively, which require no particular stiffening at the crown by means of stay-bolts.

The Hungarian State Railway has at present 235 locomotives fitted with the Polonceau fire-box; the results have been satisfactory. In addition to the easy cleaning of the crown, there is the advantage that no stays have to be used; moreover, the ribs of the crown add to the heating surface.

3. — Cylindrical fire-boxes are not used. The Hungarian State Railway did at one time build locomotives for secondary railways with half-round arched covers of corrugated plate, on the Hasswell system. In consequence of occasional want of water, cases occurred in which this crown collapsed and even became torn; the Hasswell crowns were therefore provisionally secured by means of stay-bolts to the top of the boiler, but are now being gradually replaced with Polonceau fire-box crowns.

4. — No boiler fitted with a combustion chamber exists.

5. — The material generally used for fire-boxes is copper. Trials of iron fire-boxes have been made on several railways, and some are still the object of trial at present.

6. — The fire-holes have as a rule a round shape; more rarely they are oval. With modern large and wide fire-boxes they are also very frequently rectangular, with doors sliding sideways.

The Austrian State Railway has adopted the Marek fire-door with air admission as its standard. The Hungarian State Railway has 40 locomotives with such doors.

The Austrian North Western Railway has been using a door domed outwards, with slots, made of thin cast-iron. The slots can be closed by a sliding register.

The connection between the fire-box plate and the back wall of the fire-box, where this fire door opens, is often made in the newer locomotives, by direct rivet-

ing of the two plates suitably flanged (the Webb fire-hole).

7. — The relative dimensions of the grates vary within very wide limits. These only depend on the kind of coal used. As a rule, the useful grate area is about 30 to 50 per cent of the total grate area, and the total heating surface of the smoke tubes is about 40 to 80 times the total grate area.

The locomotives have fixed grates exclusively; rocking grates are not used. Some of the railway administrations, however, use drop grates, particularly in the case of larger locomotives, which more especially give good results from the point of view of easier and quicker cleaning of the fire; this is of special importance if the coal contains much ash.

8. — Some of the railway administrations do not use intermediate supports even in the case of long boilers. On the locomotives of the Austrian State Railway, compensating supports are used.

9. — The locomotives have nearly exclusively front tube-plates placed inside with flange coming forwards, which is riveted to the front ring of the barrel.

10. — The tubes are now made exclusively, with very few exceptions, of ingot-iron or mild steel (as a rule seamless; Mannesmann or other similar steel). The fire-box ends of these tubes are protected by rings of copper, or more rarely, of iron.

The use of brass tubes was given up, quite apart from their high cost, chiefly because when lighter fuel (*lignite*) was used, the tubes became worn quickly and irregularly, till they finally collapsed and broke.

11. — The internal diameters of the smoke tubes vary as a rule between 35 and 48 millimetres (between 1 $^{3}/_{8}$ to 1 $^{7}/_{8}$ inches), and their thickness between 2·5 and 3 millimetres (between $^{7}/_{64}$ and $^{1}/_{8}$ inch). As a rule, the diameter is a little reduced at the fire-box ends or a little increased at the smoke box ends.

12. — The tubes are usually fixed in the two tube-plates by beading. Tubes with copper rings are flanged at the fire-box tube-plate.

13. — Serve tubes are not used. Cleaning them by means of a jet of steam or compressed air gave rise to difficulties and proved inefficient, so that there was a doubt as to any economy.

On the Hungarian lines of the Southern Railway, corrugated tubes of the Pogány-Lachmann type are being tried experimentally.

According to the statement made, a saving of 10 per cent was observed in the case of the locomotives fitted with these tubes; in addition, these locomotives are said to give very few sparks even when light kinds of coal are used and the spark arresters are removed. It was found too that very few cinders collected in the smoke box. In consequence of the greater elasticity of these tubes, there was stated to be less tendency towards leakage.

14. *Damage to tubes.* — Fairly serious pitting of tubes is observed in the case of locomotives which use water containing much salt (chlorides) or carbonic acid. In order to prevent this evil, trials were made with tubes made of acid-proof material.

With the same object in view, trials are being made with the Gölsdorf mud collector.

Protective coatings and other means for

preventing bad water from corroding tubes have proved unsuccessful.

The copper ends at the fire-box tube-plate become wasted by friction, particularly when doing heavy work, and when light coal is used.

15. — Galvanized tubes are not used.

Liners outside the tubes, for keeping the tubes, are not used.

The ends at the fire-box tube-plate are as a rule beaded. The smoke-box ends are but rarely beaded.

15 bis. — The leaking of tubes is generally caused by : improper firing, working the boiler too hard, sudden cooling of the tube-plate; hard feed-water, bad fuel, frequent expanding of the ends, resulting in deforming their circular shape; finally strong wear of the tube, and weakening of the plate in the interspaces. The vibration of very long smoke tubes may also produce leaks.

In order to prevent such leaks, it is necessary to see that the locomotive crews take the precautions necessary. It is also necessary to avoid, as far as possible, the use of tubes over 5 metres (16 ft. 5 in.) long, in order to prevent leaks caused by the oscillation of the tubes.

16. — The tubes are in most cases arranged in vertical rows. This arrangement has the advantage that during the generation of steam the bubbles of steam rise more easily; moreover, if the tubes are arranged in this way it is easier to clean them and remove the scale.

The spaces between the tubes vary between 66 and 73 millimetres (between $2\ ^{19}/_{32}$ and $2\ ^{7}/_{8}$ inches), and the thickness of the plates forming the interspaces of the fire-box tube-plate is nearly always 18 to 20 millimetres ($^{11}/_{16}$ to $^{13}/_{16}$ inch).

17. — As a rule, the maximum working pressure is 13 to 13·5 atmospheres. The Hungarian State Railway and the Bulgarian State Railway have locomotives with working pressures of 16 and 15 atmospheres respectively.

18. — No measures have been taken in order to reduce the formation of cracks in the corners of the tube-plates.

The repairing of fire-box tube-plates has generally to be effected in consequence of the following defects : tube-holes which are too large or are oval; ridges at the tube-holes; cracks in the interspaces; folds, grooves and cracks in the corners of the tube-plate; corrosion at the stay-bolts; bulging and stretching in the vertical and in the horizontal direction.

Oval tube-holes occur most frequently near the corners of the tube-plate, and are caused by distortion and by the expansion by heat of the different adjacent parts of the boiler.

Folds, grooves and cracks in the corners of the tube-plate are chiefly caused by the expansion and the contraction of the material in consequence of changes of temperature, and in some cases also by the repeated beading of the tubes.

19. — Extended smoke-boxes are only used by a few railway administrations.

Most of the railways give their locomotives smoke-boxes of medium length.

The Hungarian State Railway, on the other hand, build all their locomotives with extended smoke-boxes, in consequence of very extensive trials which were made with various kinds of spark arresters. These trials showed, particularly when lignite was used, that sparks were fewest in the case of extended (American) smoke-

boxes, while the steam production was not hindered by any reduction of the draft or by greater cooling of the smoke-box tube plate. These smoke-boxes also have the advantage, that they become heated less and, consequently, there is less tendency to deformation and leakiness; moreover, there is plenty of room for flue dust and, consequently, the lower rows of tubes do not become obstructed so soon.

20. — All the locomotive have steam domes, which are made as large as possible so as to have as dry steam as possible.

Domes fitted with water-intercepting devices have given satisfactory results.

A steam drier of the Clench or Gölsdorf type was been used by the Austrian State Railway; the Austrian Southern Railway and the Hungarian State Railway are trying the Gölsdorf steam drier.

21. — As a rule only sheet iron is used as lagging for the locomotive boilers.

Lagging made of blue asbestos and asbestos cloth are only used in a few isolated cases for protecting the locomotive crews.

The Hungarian State Railway made comparative trials of boilers covered with sheet iron and with asbestos years ago, and it was found that with asbestos lagging there was some economy of fuel. But subsequent experience showed that this comparatively-small saving was at least counterbalanced by the extra cost of acquiring and maintaining the asbestos lagging.

22. — No arrangements for thermal storage are used, except refractory arches in the fire-boxes of locomotives of several railway administrations.

Conclusions.

The design of the smoke-tube boilers of locomotives, now in use for a long time, is still as a rule based on the following principles.

The fire-box shells are made round topped; the inner fire-boxes are made of copper; stay bolts are generally used for the connection. Sometimes the fire-boxes are made wide, *i e.* projecting beyond the frame plates.

The locomotives have level grates; drop grates are used in some cases and not in others.

The smoke-tubes are made of ingot iron or mild steel; brass tubes are only used as an exception. Apart from a few solitary experiments, only smooth tubes are used.

Copper ends are generally brazed to the iron tubes at the fire-box side. The tubes are in most cases arranged in vertical rows.

The working pressure of the more recent locomotives varies between 13 and 16 atmospheres.

No special measures, apart from those generally known, are taken to prevent any damage to the boilers; the same applies to the repair of boilers.

With the more recent locomotives extended smoke-boxes are used in the majority of cases.

The heat insulation of the boiler consists chiefly of sheet iron, with a non-conducting layer of air in between. Asbestos lagging is only used in a few cases.

Refractory arches are often used in the fire-boxes.

The President. (In French.) — As Mr. Vaughan is absent, Mr. Crawford undertook to give a summary of his report, but he has not yet been able to finish his work. I therefore propose, gentlemen, in order not to waste time, that the discussion should be started at once. (*Approval.*)

Mr. Zehnder, Bavarian State Railway. (In German.) — In his report, Mr. Steinbiss briefly mentions the results given by wide fire-boxes, and mentions against them leaks at tubes and the frequent troubles with stay-bolts. As having a large grate area necessarily involves the use of a large fire-box, we should like to have some more definite information about the disadvantages observed and to know whether these disadvantages turn up on the large scale or only in individual cases.

Mr. Steinbiss, *reporter*. (In German.) — As regards the wide fire-boxes used on the Prussian-Hessian State Railway, there have been complaints about leaky tubes. The Prussian State has tried to remedy this by replacing the double fire-door by a single one. That is the present state of the question. In Bavaria, the single door is already in use. It is possible that the trouble in question is also due to the fact that we have less experience in the construction of these fire-boxes than the Americans.

Mr. Noltein, Moscow-Kazan Railway. (In German.) — I should like to remark that we also have a large number of locomotives with wide fire-boxes, extending beyond the frame plates, and that far from giving any trouble, these fire-boxes work very well.

Mr. Slobodsinsky, Russian State Railway. (In French.) — On the lines of the Russian State Railway, we have many locomotives with wide fire-boxes. Up to the present we have had no trouble with these fire-boxes.

Mr. Herdner, Midi Railway. (In French). — I may mention that we also use wide fire-boxes on the Midi Railway. But this fire-box is not fitted with a rectangular grate. It is a fire-box which is between the frame plates in front and only extends beyond them at the back. The grate has hence an approximately trapezoidal shape.

This system allows us to avoid the dead angles found in the front of the wide fire-boxes when the grate is rectangular.

Fire-boxes of this kind have given very good results until now. The stay-bolts, in particular, have acted very satisfactorily. Cases of fracture have been very rare.

Mr. Steinbiss. (In German.) — I would add that we attribute the leaks to the use of two fire-doors. We found that these two doors let in too much air, and so we adopted one single door.

Mr. Greppi, Italian State Railway. (In French.) — The Italian railways have at present in use 288 locomotives fitted with wide fire-boxes extending beyond the frame plates. Of these, 150 are of the *Prairie* type, for express trains, and 138 are locomotives with five coupled axles. The oldest of these locomotives has been in use since February 1907. All the fire-boxes have worked well.

We are at present building locomotives of a new design with trapezoidal fire-boxes of the very type described by Mr. Herdner.

The President. (In French.) — The others are rectangular?

Mr. Greppi. (In French.) — Yes, but they have nevertheless given good results.

Mr. Rhor, Alsace-Lorraine State Railway. (In German.) — The reports would

show that all the German administrations have given up Serve tubes. Now, we have been satisfied with them and continue to be so. Serve tubes give excellent results, subject to their being properly cleaned; this is best done after every run, while the locomotive is still hot. No deposits of soot, etc., are then formed. I am decidedly in favour of the continued use of Serve tubes.

Mr. Slobodsinsky. (In French.) — How many locomotives are fitted with these tubes?

A delegate. (In French.) — What is the length of these tubes?

Mr. Rohr. (In German.) — We have 165 such locomotives in use, dating from four to seven years; the tubes vary in length from 3·8 to 4·2 metres (12 ft. 5 in. to 13 ft. 9 in.) between tube-plates.

Mr. Chabal, Paris-Lyons Mediterranean Railway. (In French.) — We have a very long experience of Serve tubes which have been used for all the locomotives we have had built since 1889. We have at present about 1,800 locomotives fitted with these tubes, in use on the Paris-Lyons-Mediterranean Railway, and we have never had any trouble. Steam is used for cleaning them. It may sometimes be necessary to use a rod to loosen any rather harder deposit, but that is all.

Mr. Herdner. (In French.) — On the Midi Railway also, we have a large number of locomotives fitted with Serve tubes, and in this connexion I wish to draw attention to the following sentence in Mr. Nadal's report : " but several railways, more especially the Eastern, the Midi and the Italian State, think that these tubes, owing to their excessive rigidity, accelerate the deterioration of the fire-box tube-plates."

It is in fact brought against Serve tubes, which are stiffer than ordinary tubes, that their successive expansions and contractions produce deformations in the tube-plate and hence promote the production of fractures between the holes of the extreme vertical rows on the right and on the left.

Now in order to ascertain what truth there was in this statement, we took an opportunity of ordering six locomotives similar to existing locomotives, in order to replace the Serve tubes by smooth tubes. These tubes had an inside diameter of 43 millimetres (1 $^{11}/_{16}$ inches), and in accordance with a custom which is very general in Belgium and even in England, we gently bent these tubes upwards, giving them a sagitta of about 30 to 35 millimetres (1 $^{3}/_{16}$ to 1 $^{3}/_{8}$ inches), and we tied together the two front and back tube-plates by means of four solid stays, spaced at regular intervals. We thought that in this way our two tube-plates would be made immovable, while the smoke-tubes would become more or less bent as they expanded and as they contracted.

Now experience has shown that these plates cracked in the same way and at the same points as with the Serve tubes. Accordingly, when we subsequently had new locomotives built, we resumed the use of Serve tubes which have the advantage of presenting a greater heating surface.

Mr. Greppi. (In French.) — On the Italian State Railway, we have nearly 390 loco-

motives in use, which are fitted with Serve tubes. The tubes have worked very well.

As the tube-plates of a certain number of these locomotives gave us trouble, we at first thought that this was the fault of the Serve tubes; but this is by no means certain, as we have had the same trouble with similar locomotives not fitted with Serve tubes.

We have one type of locomotive with Serve tubes 2·80 metres (9 ft. 2 1/4 in.) in length which we are still building, but we have given up the use of these tubes in the newer types, because in their case the length of the tubes always exceeds 4 metres (13 ft. 1 1/2 in.).

Mr. Lavialle d'Anglards, Portuguese Railway Company. (In French.) — I should like to know whether solid or hollow longitudinal stays are used in France.

Mr. Herdner. (In French.) — No, solid stays.

Mr. Lavialle d'Anglards. (In French.) — I may mention in this connection that on our railway, about ten or twelve years ago, we systematically used solid longitudinal stays for all our locomotives and that the results were not satisfactory.

Two methods were adopted. The first consisted in connecting the fire-box and smoke-box tube-plates by means of five solid stays distributed among the last-but-one bottom circular row of tubes.

The appearance of fractures was not delayed by this staying; one might almost conclude the contrary.

Six or seven years ago, the arrangement of stays was modified; the four or five were distributed in the central part of the tube-plate, as a rule two in the middle vertical row and two others at equal distances between this row and the edges of the plate.

The results were also not satisfactory; it even seems that this arrangement facilitates the appearance of cracks in the lower parts where they are less easy to repair than in the upper lateral parts.

At present, these systems of staying have been given up and fractures only seem to occur after longer distances have been run.

Mr. Salomon, French Eastern Railway. (In French.) — As regards Serve tubes, I may mention that on the French Eastern Railway we have 500 to 600 locomotives which are fitted with these tubes. We think that they tend to deteriorate the tube-plate a little more; but that is more an impression than anything else, for we have not made any observations definitely establishing this fact.

In any case, as regards the proper condition of the tubes, our locomotive sheds and minor workshops have no difficulty in keeping the Serve tubes as tight as the ordinary tubes. We accordingly continue to use Serve tubes, without longitudinal stays, in all our recent locomotives.

Mr. Chabal. (In French.) — As regards this question, I may add that on the Paris-Lyons-Mediterranean Railway we have about 1,800 locomotives which are fitted with Serve tubes; 80 of these locomotives, the oldest, have run on the average 600,000 kilometres (372,800 miles) without the tube-plates requiring any repair. I think that this mileage is the greatest ever made without any repair; and this proves that the Serve tubes exercise no dele-

terious influence on the proper condition of the boiler.

The President. (In French.) — You use no stays?

Mr. Chabal. (In French.) — No.

Mr. Fowler, *reporter.* — The results obtained on the Midland Railway with Serve tubes have been very unfavourable. Tubes 12′ 2″ in length were used.

Mr. Salomon. (In French.) — That is however the same length as in our locomotives.

Mr. Herdner. (In French.) — Most of our tubes are also more than 4 metres (13 ft. 1 1/2 in.) long.

Mr. Salomon. (In French.) — Care must only be taken to clean the Serve tubes frequently by means of a steam jet.

The President. — Mr. Fowler, how do you clean your boilers, with water or with steam?

Mr. Fowler. — By means of steam jet, but we had so much trouble with Serve tubes on account of the excessive leakage that we were forced to discontinue their use.

Mr. Koechlin, French Northern Railway. — (In French.) — I think that the French Northern Railway was the first to use Serve tubes. We feel convinced that given equal weights, we can get much more out of one of our locomotives fitted with Serve tubes than out of one of our locomotives fitted with ordinary smooth tubes. That is a question of power which is of paramount importance to us. We have very fast trains, and for those trains we have always used locomotives fitted with Serve tubes. We think that it is owing to these tubes that we have been able to achieve such fine results in the way of speed.

We have recently tried smooth tubes in another series of locomotives which till then had only been fitted with Serve tubes; but we at once found that the boilers gave less steam.

Mr. Greppi. (In French.) — We have had in use, for eight years, a number of tank locomotives and of locomotives with four coupled wheels and bogie, which were fitted with Serve tubes from the start, the tubes being 2·80 and 3·20 metres (9 ft. 2 1/4 in. and 10 ft. 6 in.) in length respectively. The tube-plates have worked very well; most of the original plates are still in use.

In our most recent types of locomotives, we no longer used Serve tubes, but that for operating reasons. In the case of locomotives of the more powerful types, we have had to increase the length of the tubes of these locomotives to 5 metres (16 ft. 5 in.) and upwards, and we feared we would have difficulties with Serve tubes of this length. Hence we adopted smooth tubes in this case.

Apart from this, we have during the last few years preferred smooth tubes even for locomotives having shorter tubes, in order to facilitate the re-utilization of shortened tubes, and on account of certain difficulties which we encountered in ordering tubes. We could in fact only obtain Serve tubes from much fewer sources than smooth tubes. Moreover, the question of price has to be considered.

Mr. Chabal. (In French.) — On the Paris-Lyons-Mediterranean Railway we have altered a certain number of old goods

locomotives with three coupled axles. As and when these came in for repairs, when it was necessary to deal with the tube-plate, we replaced the smooth tubes by Serve tubes without making any other alteration in these locomotives, except of course altering the diameter of the holes. I can say that in practice our drivers are able to haul, with these locomotives, 10 per cent heavier loads. I am talking of trains run every day, consequently of current practice.

Mr. Fowler. — The following are the conclusions which Mr. Vaughan, reporter for America, has arrived at :

The type of boiler generally used has a round-top fire-box with radial roof stays, athough about 15 per cent of the locomotives are fitted with Belpaire boilers. It has been found that the throat plates of the Belpaire boilers crack more easily.

Seams. — Welded rings are being tried.

Domes. — Every locomotive has a dome.

Stiffening. — The back plate of the fire-box and the tube-plate of the smoke-box are stiffened, usually by rod staying, less frequently by gusset plates.

Fire-box staying. — The crown stays are button-headed on the fire side. On the shell side they are riveted or fitted with a nut.

Stays. — As a rule wrought iron is used, as normally specified. At some points flexible stays are put in.

Inside fires boxes. — Steel plates are universally used, usually 9·5 millimetres (3/8 inch) thick. The life varies from five to eight years. Wide fire-boxes are used on a large scale.

Fires doors. — The doors are generally on hinges.

Water spaces. — The water spaces between the inner and outer fire-boxes have been increased during the past few years from 3·5 to 5 inches (88·9 to 127 millimetres).

Tubes. — Mild-steel or charcoal-iron tubes are used. The ends of the tubes (with copper ferrules) are expanded and beaded.

The President. (In French.) — Gentlemen, you have just heard the summary of Mr. Vaughan's report which Mr. Fowler has been kind enough to give to us. If nobody has any remarks to make on the subject of this summary, I propose that we adjourn till this afternoon.

As I have already stated, we propose to draw up general conclusions concerning littera *A*, which will summarize the conclusions of the different reporters.

Meeting held 8. July 1910 (afternoon).

Mr. Ernest GERARD, vice-president, in the chair.

The President. (In French.) — Gentlemen, before we begin our discussions, I want to raise a preliminary question.

Littera *B* of question VI includes the very important subject of superheating, and its importance is such that the discussion of this littera may occupy us during the whole of our tomorrow's morning meeting and perhaps also during part of our tomorrow's afternoon meeting. Under these conditions, I propose that we limit ourselves today to the consideration of littera *C*.

If nobody objects, this course will be adopted.

Mr. Archbutt, *reporter for Great Britain.* — The replies received from the administrations reported on shew that the practice of the different railways in Australasia, Great Britain, India and South Africa varies very much in regard to water-softening, some having adopted it extensively and others not at all. Lime and soda are the chemicals invariably used, no others being sufficiently cheap. Lime removes only the hardness called " temporary " *viz* : that caused by calcium and magnesium carbonates, but as its use introduces into the water no new substance, the water purified by lime causes no secondary effects and is practically as good for boilers as distilled water. On the other hand, when the hardness called " permanent " has to be dealt with, *viz* : that caused, for example, by calcium and magnesium sulphates, sodium carbonate or caustic soda must be used, and the purified water then contains sodium sulphate, which causes forming to commence when the water has reached a certain degree of concentration. The proportion of soluble salts which is necessary to cause forming depends upon the amount of steam space in the boiler, the rate of steaming, and also to some extent upon the nature of the salts, sodium carbonate causing forming more readily than sodium sulphate, and sodium sulphate more readily than sodium-chloride, but generally speaking, experience seems to point to a concentration equivalent to from 214 to 500 parts of soluble salts per 100,000 of water as being sufficient to cause the locomotive boiler to prime severely and then the water must either be blown off or changed. For this reason, it is found necessary to limit the quantity of soda used in softening to an amount which will not prevent the engine from running a reasonable mileage before washing out, and this means that bad water can only be partially softened. To remedy this defect, some railways have tried using barium compounds in place of soda or soda ash, but the cost has always been found prohibitive; in fact, with very hard water, it may be cheaper to distil the water in some form of multiple effect apparatus than to soften with baryta. The Cape Railways do, in fact use Mirrlees-Watson-Yaryan distillers in one district where the water obtained in dry seasons is very bad.

The experience of those railways which have adopted water-softening shews that great saving is effected thereby in the cost of re-tubing boilers and removing incrustation, fewer stays are found broken and leakage is practically stopped. No information seems to be forthcoming as to the saving in fuel. Two administrations report a large saving through being able to use, after softening, a bad water obtained at small cost instead of having to purchase more expensive water of naturally better quality.

Since the date of the last report (1900), the use of water-softening plants has considerably extended amongst the railways reported on, and we do not doubt that it will continue to extend as the saving which is capable of being thus effected becomes better realised. One reason why progress in the past has been slow, is the fact that water-softeners were regarded as machines which required no scientific

control and could be efficiently run by the labourer in charge. Most railways now employ chemists, and it is realised that the water-softeners should be placed under the supervision of the chemical as well as of the engineering staff. Those railways which have been working on these lines, find that the results obtained well repay the cost entailed by water-softening.

To obtain the best results, water-softening should be used in conjunction with a system of changing the water in the boilers before it has become too concentrated in regard to sodium salts, or saturated as regards that part of the calcium sulphate which cannot be economically removed without unduly charging the water with sodium salts. To enable the water to be changed with the necessary frequency, and without engines spending too much time in the shed, the boilers must be filled up with hot water. When the amount of sodium salts or calcium sulphate in the original water is excessive, undue concentration can only be prevented by the use of blow-off or scum-cocks, of some description. The practice adopted must be based upon and controlled by a systematic chemical analysis of the principal waters used by the locomotives in each district.

Disincrustants are used in the boilers by a few railways, those most commonly employed being preparations containing tannin or soda alone, or a mixture of the two. The experience of some administrations has been favourable, others have given up the use of disincrustants in favour of water-softening.

Several railways have contributed analyses of water which, without containing mineral acid are found to be specially corrosive. A water of this character obtained by the Midland Railway of England from a tunnel in the Millstone Grit and associated shales shews nothing in the analysis which would lead one to expect it to be specially corrosive and yet it attacks the boilers in a remarkable way, causing general corrosion of the barrels below the water line, attacking especially the rivet heads and stays. The only explanation which has suggested itself to account for this action is the fact that the water forms a soft unprotective scale and contains sufficient sodium salts to render it a good electrolyte. It does not contain a remarkable amount of carbon dioxide or oxygen, but doubtless these are the active agents in causing the corrosion.

For the prevention of corrosion, some railways obtain good results by coating the boiler plates with Portland cement; but in one case it was found that in the boilers in which this was used it washed off and was a failure. A coating of graphite and boiled linseed oil has been tried, but was found to percolate through the seams and joints and cause leakage. On one line the boilers are painted inside with tar and graphite. Zinc plates and plugs have been tried by several railways, with unsatisfactory results. Some administrations have found the addition of a definite excess of slaked lime to the water distinctly advantageous in preventing corrosion, especially in the case of natural soft waters.

This has a good effect, for example, in reducing the corrosive action of the water I have just referred to used on the Midland Railway.

The majority of the railways still use

cold water for washing-out boilers, but the use of hot water is extending.

On many lines the use of blow-off cocks or scum-cocks to prevent priming is necessitated by the bad quality of the water which has to be used.

The President. (In French.) — The statements just made by Messrs. Archbutt and Fowler are practically only a reproduction of their conclusions. I therefore think it unnecessary to have them translated. I now call upon Mr. Antochine.

Mr. Antochine, *reporter.* (In French.) — I will limit myself to reading the conclusions of my report.

A very large majority of the Russian railways have good water available for feeding the boilers, which is nearly absolutely pure, and does not affect the wear of the boilers, even in twenty-five years of use; consequently many of the railways do not occupy themselves with keeping statistics relating to the influence of the water on the life of the boilers.

A minority of the railways have only hard water available and consequently (as compared with the railways just mentioned) have been quick to ascertain the injurious effect of such water; these railways have tried the frequent washing out of boilers, and the purification of the water, in order to prevent damage to the boilers or at least to reduce it. The chemical processes of purification have proved that it is necessary to avoid the presence of an excess of soda in the purified water, and, consequently, many of the railways only effect a partial purification of the water by means of soda.

At three of the stations on the Central Asia line, the very hard water is purified by distillation.

Purification of the water by means of zinc, barium salts, Campeachy wood, petroleum residues, etc., has only been tried in a few exceptional cases.

Boilers are washed out, either with hot or with cold water, after running 500 to 800 versts (330 to 530 miles) on some lines where only hard water is available.

Blowing off the boilers under pressure is not a general practice.

Hard water has a great influence on the corrosion of the boilers and on the regularity of the train service. The residues left on evaporating hard water which are in the form of scale, attack the iron walls of the boilers immediately, probably by a chemical action; on the other hand, the walls made of copper, which are subjected to the immediate action of the fuel, have a greater tendency to burn away in consequence of the reduced conductivity produced by the adherent scale.

These two cases result in damage of different kinds, namely: in the case of iron walls, in corrosion, cracks and grooving, rarely fissures; in the case of copper, on the other hand, in fissures, cracks and in burning away, according to the thickness.

The places where damage occurs are those which are subjected to repeated bending from the periodical heating and cooling of points where scale can collect without difficulty; for instance the lower part of the barrel, that of the fire-box and the crown of the latter.

As protection against such damage, the following may be mentioned: stiffening the walls of the boiler so as to reduce the amplitude of the flexure when heating up; the use of mud pockets for the residues obtained by the evaporation; as well as a design of boiler which makes it easier to scrape and wash out the scale, and prevents the deposit of the latter.

As regards stays, the Russian railways have not as yet been led to consider the use either of a complex shape (flexible stays) or of materials other than iron and copper.

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Mr. Papp, *reporter for Austria, Hungary, Bulgaria, Rumania, Servia and Turkey.* (In German.) — The following is a summary of the answers received :

1. — The purification or rather the softening of the feed water is as a rule effected by the addition of soda, or if required, of lime. The substances are added, in the proportions prescribed, either in the boiler or tender, or else there are special apparatus provided for purifying the water. The purification is seldom effected in the water tanks of the water-supply station, because although this is probably an inexpensive proceeding, the pipes become blocked up easily.

The control of the proper purification consists chiefly in making frequent analyses of the purified water and also in the careful supervision of the apparatus used.

The Breda, Dervaux-Reisert, Desrumeaux, Kennicott, Wehrenpfennig, Stingel, Beranger, Pollatschere, Adorjan and Pfeiffer methods are used for softening the feed water for boilers.

In order to ensure proper working, the apparatus is inspected from time to time by experts, and analyses are made both of the original and of the purified water.

In the case of automotor boilers, the feed water is purified in special tanks, by means of soda and lime.

It is also noted that unsatisfactory results are obtained if attempts are made to purify water containing sodium chloride or water contaminated by the drainage from manufactories. At such places, new wells are sunk or water is brought from a distance in order to obtain a supply of good feed water.

The need for water purification is every year becoming less, because care is taken year by year that all water-supply stations shall have a supply of good feed water, either laid on from a distance or obtained by sinking deep wells.

2. — It is generally recognized that it is advantageous to purify the feed water, but no administration is in a position to give any figures as to the economy realized, and that chiefly because the purifying apparatus, which are used in rather large numbers, have only been in use too short a time to enable one, with the help of the results hitherto obtained, to draw any definite conclusion as to the different systems compared and to the cost of operating them. We may however note, that the conditions of the boilers has become materially improved since the proper purification of feed water was undertaken.

The cost of maintenance of the boiler barrel is very low, and this barrel has such a long life, that boiler plates even thirty years old are to be found, which are then replaced in the interests of safety. The cost of maintenance of the fire-boxes, particularly of the copper fire-boxes is very great, and their life is short. They can seldom be used for more than ten years, and in many cases fire-boxes have now to be renewed in five and even in three years.

It is impossible to give exact figures as to the cost of repairs to the boilers; they vary per boiler and per five years between 1,100 and 9,500 kronen (between £46 and £396).

3 to 5. — As regards the treatment of water containing calcium and magnesium sulphates, chlorides or nitrates, soda is used exclusively, and priming is prevented by taking care that no excess of soda is added to the feed water.

Some of the administrations do not purify such waters at all, and try, as far as possible, to avoid their use.

6. — The different nostrums, some of them secret, which are sold under various names, for preventing the formation of scale in the boiler, consist chiefly of impure soda, organic substances containing tannic acid, and sometimes of cellulose or other insoluble substances.

The results are always unfavourable from the economic point of view. These nostrums must also be looked upon with suspicion as regards the possibility of promoting ultimate corrosion.

7. — The use of the different disincrustants was not observed to result in greater leakage of tubes or stays, nor have they caused any other damage to the boilers.

8. *Defects in the boilers.* — They can be divided into two chief groups : those which as experience shows always arise in the same way and usually at the same points, and those which turn up unexpectedly and in single instances.

The first group includes those defects, the origin of which is to be sought in the mechanical action of the heat or in the chemical action of the water and the fire, that is of the fuel. The expansion of the different constituent parts of the boiler, in spite of the different devices which are intended to make free expansion possible, can not always take place without doing harm. In consequence of the design, there will be considerable resistance at some points and injurious strains will result; these in course of time will produce folds and grooves, and finally cracks.

The second group comprises the sudden and unexpected defects, chiefly due to the use of material of bad quality and to bad workmanship. Cracks between the rivet holes are caused either by the bad quality of the material, or by bad workmanship, or by improper treatment.

Cracks in the barrel along the caulked edges. They are caused either by the plates having been bent at too low a temperature or by too sharp bends. Longitudinal cracks at the sides, above the boiler supports, are caused by want of proper support. Too forcible caulking can also produce cracks along the caulked joints comparatively easily, as the ingot-iron plate used is rather sensitive.

The fracture of roof stay-bolts and of tube-plate stays, the fracture of angle and plate stiffening, the appearance of unexpected cracks very often also depend on the design of the boiler and on the way its parts are made or on its being worked too hard. Sudden great demands followed by a quick drop of temperature are exceedingly injurious.

The defects observed in boilers can be classified into four groups :

1° Cracks and fractures occur principally in the corners of the fire-box tube-plate, the fire-hole ring and the throat plate; also in the interspaces of the tube-plates, and at the edges of the plates, extending there from the rivet holes and the stay holes;

2° Pitting, in various forms, is found inside the boilers chiefly in the lower portions of the barrel at the bottom; more rarely in the steam space of the boiler, and along the rivets and joints of the fire-box. These phenomena appear, when the metal used is not homogeneous, at the points where different metals are in contact; they are also promoted by quick and frequent variations in the temperature, and by the

influence of certain kinds of feed water.

External corrosion at the lower parts of the fire-box plates is chiefly caused by the use of fuel containing sulphur;

3° Grooves, pitting and folds are found more especially at the corners of the fire-box plates, because when the plates are bent, a number of minute sharp-edged cracks are formed on the very surface and these are widened and deepened by the effect of the fire. Similar grooves and pitting are also formed on the water side of the fire-box, at the corners of the shells and the throat plate.

Vertical grooves are also often formed along the stay-bolt rows;

4° General surface corrosion is found chiefly along the whole of the bottom half of the barrel, at the corners of the fire-box plates and at the fire-box plates either in a vertical direction between the stay-bolts, or in a horizontal direction in the lower part; also at the bottom of the smoke-box around the washing-out plugs.

Corrosion caused by the fire is often found at the tube-plate and the other fire-box plates; these are caused chiefly by forced draft or by the action of fuel containing sulphur.

9. — Records are generally kept about the boilers undergoing repair, and their defects, and in some cases sketches are made.

Different administrations adopt different systems for the purpose.

10. — There is no general tendency towards modifying the design of locomotive boilers in order to prevent the defects observed; only in a few cases are a few details altered. Several administrations, in order to prevent corrosion at the bottom of the barrel and also at the lower inner edge of the fire-box, use thin plate riveted direct to the frame, about 5 millimetres ($^3/_{16}$ inch) thick, made of steel in the barrel and of copper in the fire-box. These protective plates have given good results, but their use was given up in the case of the locomotives of the Hungarian State Railway, because to remove them when the boiler was examined was a matter of difficulty, and to put in fresh plates was impossible.

At present many hold the opinion that the increasing defects which are caused by the continual increase in the working pressure, particularly at the fire-box by the high temperatures, can at least in part be avoided by the use of superheated-steam locomotives, and that the maintenance of boilers will then give more favourable results.

The feed water is delivered into the boilers of most locomotives at the centre line either at the middle of the barrel or in the front third. At the point of delivery there is generally both a check and a stop valve. The Austrian North Western Railway has locomotives with the feed water introduced at the bottom of the barrel. This administration, as already stated, is also making trials with the Gölsdorf mud collector; the feed water is led through this apparatus to the boiler. Attempts to introduce the feed water into the boilers through the smoke-box tube-plate and trials with feed water heaters are at present being made on the Hungarian lines of the Austrian Southern Railway.

Injectors are used generally for feeding the boilers, the non-lifting kind being chiefly used.

The Hungarian State Railway is at present trying two kinds of feed-water heaters. One of these Brazdá type, in which

the feed-water is heated in a special tank by means of live steam, and then after it has become sufficiently heated and the pressure has become equalized it is admitted direct into the boiler. This has the advantage that the whole of the scale is formed in the feed-water heater, and is only deposited in the locomotive boiler in the form of fine mud, no hard scale being formed.

The other with which trials are at present being made is the Caille-Potonier apparatus, in which part of the steam from the exhaust is used for heating the feed-water. The water which is heated to 90° C. (194° Fahr.) or more is then delivered to the boiler by a special pump.

Neither of these apparatus has yet been fully tested, so that no final opinion can be expressed as to their value.

11. *Washing out locomotive boilers.* — The time between two washings out varies between five and twenty days, according to the quality of the feed-water. If the boiler is washed out with cold water, the time allowed before the water is drawn off is up to twelve hours, according to the size of the boiler, and another two to four hours are allowed for the cooling of the empty boilers, so that about sixteen hours are spent altogether. The pressure used depends on the dimensions of the boiler and the number and distribution of the washing-out holes, and varies between 1 and 8 atmospheres. If hot water is used, the water required is either provided by operating the apparatus by another locomotive, which is in steam, or else the Wittenberg and Schillhan system is in use. In this case, the steam still left in the boiler which is to be washed out, after the locomotive has stopped, is used to heat at 70 or 80° C. (at 140 or 176° Fahr.) the water in the tender; this is then used for washing out the boiler which has been emptied and sufficiently cooled off by means of turbine pumps, driven by an electric or a petrol motor. When this system is used, the total time required from the time the locomotive stops running till it is ready again, can be reduced to six hours. The pressure of the water used for washing is generally 2 to 4 atmospheres (28·4 to 56·8 lb. per square inch).

These newer methods for washing out boilers are, however, still in the experimental stage and it is hence not yet possible to decide which of them is best from the points of view of utility, of the requirements of the traffic, and of economy. The experiments are, however, going to be continued on a larger scale.

The locomotive boilers are washed out on the average after every 600 to 700 kilometres (370 to 435 miles) run; but this distance is increased to 1,000 kilometres (620 miles) in the case of good water, but reduced to 350 or 480 kilometres (217 or 300 miles) if the feed-water is very bad.

The locomotive with the Brazdá feed-water heater is only washed out after it has run 6,000 to 8,000 kilometres (3,700 to 5,000 miles). Distances of even 10,000 kilometres (6,200 miles) have been run between two successive washings out, without finding any hard adherent scale in the boiler; a good deal of mud was alone deposited in the lower parts of the boiler, and this could easily be washed out. At intermediate times some of the boiler water is allowed to run out, at reduced pressure, and this at the same time removes part of the deposited mud. This trial is also not concluded yet.

12. — Blowing off the boiler is a proceeding only adopted by a few railway administrations. Its main object when muddy or very alkaline feed water is used, is to remove mud or to prevent the concentration of injurious substances in the water so that priming may be prevented; but this method has not proved very efficaceous.

It is certainly better, if enough time is available, to run off all the water and wash out the boiler with hot water.

Some railway administrations on principle only allow the water to run out when there is no longer any pressure in the boiler.

The blowing-off of the boiler, as well as the removal of the water is practically always effected by means of blowoff cocks which are fitted, low down, to the front plate of the fire-box, and which in many cases are operated by means of a long key from outside the frame plates. Some locomotives have such cocks also at the bottom of the barrel.

13. — The only railway that mentions any water specially corrossive to boilers is the Austrian North Western Railway. This administration gives the following analysis of a water, which is purified by means of lime and soda :

	Parts per 100,000.
Lime Ca O	14·94
Magnesia Mg O	11·02
Potash K_2 O	22·73
Soda Na_2 O	6·68
Sulphuric acid SO_3	58·30
Chloride Cl	5·75
Carbonic acid CO_2	15·72
Silica Si O_2	1·72
Ammonia NH_4	1·72
Total solid residue	120·08
Ditto after ignition	115·22

16. — Copper is as a general rule used for stay-bolts; in the case of ingot-iron fire-boxes, however, ingot-iron stay-bolts are also used. Stay-bolts of manganese bronze (4 per cent of manganese) are being tried; as far as present results go, this metal is only suitable for stay-bolts which are subjected to the very great tensile stresses. In the case of stay-bolts subjected to smaller stresses, it is preferable to use copper, which is more easy to work and yet remain tight. Records on this point are not kept.

The use of electrolytic copper for stay-bolts is not to be recommended.

Fractures of the stay-bolts most frequently occur in the top horizontal and in the outside vertical rows, and the sides at these points then begin to bulge. The fracture is usually immediately at the inner side of the fire-box plates. In order to facilitate the detection of such fractures, a hole is drilled through the whole length of the stay-bolt and this hole is rivetted up on the outer side. Issuing steam then shows if a stay-bolt is broken, and a new one is at once put in; the immediate renewal is particularly important if the fracture is in the top or the outer rows of stay bolts.

Flexible stay-bolts were also tried as an experiment, but it was found that they soon became coated with scale to such an extent that they lost all their flexibility and consequently no longer acted.

33. — Several administrations have tried Spiegelhalter refractory linings for fire-boxes; these consist of a mixture of kaolin, kaolin bricks, graphite and asbestos cemented on to wire netting secured to some of the stay-bolts at the lower part of the fixe-box plates, so as

to extend up a little beyond the layer of coal.

It was found that when coal containing much sulphur, but not of the caking kind, was used, the protective lining continued to adhere fairly well, and the covered parts of the fixe-box walls remained undamaged, while the steam production was not affected unfavourably. With caking coal, or with coal containing much slag, this slag became largely deposited on the protective lining. As a consequence, this lining, which originally was about 5 centimetres (2 inches) thick, became much thicker and interfered with the fire, and consequently had a bad effect on the steam production. A good deal of force is required to remove this accumulated slag, and this damages the lining and separates it from the walls. It was, moreover, observed that with certain types of locomotives, when the protective lining in question was used, leaks at the tubes occurred with remarkable frequency; it has not yet been definitely ascertained as to what this is due.

The experiments with the Spiegelhalter protective lining are not yet concluded, and its economic effect has not yet been determined.

Conclusions.

The observed defects in locomotive boilers occur typically on all railways in practically the same generally known way. Special phenomena of this, in the case of individual boiler designs, were not reported and do not appear to have been observed. Special means for preventing defects in boilers do not exist.

The feed-water is purified either in the boiler and in the tender, more rarely in the water-towers, or in special water-purifying installations, of which there are however but few. No data are available as to the influence of the different purifying processes on the maintenance of the boilers and on the economic results.

The chief disincrustants are soda and lime. So-called anti-fouling compounds are as a rule not used.

The boilers are washed out both with cold and with hot water; there is a tendency to extend the latter system and in some cases special installations are provided for the purpose.

Apparatus for heating the feed-water, and for separating the boiler scale, are being used experimentally.

As material for stay-bolts copper is chiefly used; manganese bronze only to a very limited extent.

Protective linings for the fire-box walls are only in use experimentally.

Mr. Nadal, *reporter*. (In French.) — The use of good water is essential if the boilers are to have a long life. Although it is impossible to determine accurately the saving effected by using purified water, I can quote, in this connection, the following fact. In 1902, the French State Railway set to work 30 compound locomotives, with four cylinders, working pressure 15 kilograms per square centimetre (213·3 lb. per square inch); about half of them being attached to the Saintes depot and the other half to the Thonars depot; at the former, the water had 30 to 35° of impurity, at the latter 15 to 20°. The tube-plates of the Saintes locomotives had to be replaced after runs of 200,000 to 250,000 kilometres (124,300 to 155,350 miles); but those of the Thonars locomotives only after 350,000 to 400,000 kilometres (217,500 to 248,600 miles). The gross economy can thus be estimated at 40 per cent.

The purification of water of mediocre quality (above 25° of impurity) is nearly always to be recommended; it becomes indispensable when the water contains a considerable amount of salts of the alkaline earths (above 40° of impurity).

Waters containing carbonates are treated with lime; those containing sulphates are treated with sodium carbonate; generally both reagents are used simultaneously, or as the impurities present may make advisable.

This purification is after all a rather delicate chemical operation, and if good results are to be obtained, much care must be taken (in particular frequent analyses of the water in question, of the lime used as reagent and of the purified water), on the one hand because the quality of the water which has to be treated is generally liable to vary within rather wide limits, on the other hand, because much trouble arises if one of the reagents, namely sodium carbonate, is used in excess. For if it is so used, priming results, and it is better to use slightly less than is required.

In Europe, the purification of water is on the whole an exception. On the other hand nearly all the railway administrations use disincrustants placed direct into the boilers or into the tenders.

There is a great number of such disincrustants. Their object is to make the scale softer and less adherent; they have some action, but are not quite effective. Systematic removal without pressure, that is to say running off, without pressure, part of the boiler water in order to clear away deposit, materially improves the effect produced by disincrustants. Unfortunately such systematic removal is rather difficult to carry out in practice in a regular manner, and the boiler has to be fitted with special appliances for the purpose.

It may be mentioned that in Algiers the waters are as a rule of very bad quality and very corrosive. It is by no means rare for them to have over 100° of impurity. Moreover, they contain much magnesium and chlorine, so that they are very corrosive and produce much scale.

Mr. Steinbiss, *reporter*. (In German.) — 1. *Processes for softening and purifying the water*. — It is the general opinion that proper and careful purification of the water *before* it is used is the best means for preventing the formation of scale, which has a bad influence on the working, increases the cost of maintenance and produces damage which shortens the life of the boilers.

At many places, suitable water is available, so that maintenance and working are satisfactory; there are comparatively-few places where bad water must be used, either because better water is absolutely not to be obtained, or could only be brought from elsewhere at an excessive cost. The processes for purifying water form a useful means for improving such waters.

Among the salts dissolved in water the most important as regards the formation of scale are calcium sulphate ($Ca\ SO_4$), and acid calcium carbonate ($Ca\ CO_3\ H_2\ CO^3$); silicates, calcium chloride, magnesium sulphate, magnesium chloride and acid magnesium carbonate are found in smaller quantities. In a few cases sodium chloride ($Na\ Cl$), humic acid, and iron compounds turn up in injurious quantity.

As a rule, the administrations, with

which I have communicated, soften and purify the water by the addition of quick lime, sodium hydroxyde and sodium carbonate in the well-known apparatus. These apparatus differ chiefly in the manner in which the chemicals are added to the water which is to be purified; the lime and soda may be added separately or both together; the process may be automatic or not. Very much the same reactions take place with the magnesium salts as with the calcium salts, but not as completely; chlorides and sulphates are both acted on.

Instead of sodium carbonate, barium carbonate is also used in some installations.

Barium chloride is also used to a small extent in such processes. This reacts with the calcium sulphate ($Ca\,SO_4$), and barium sulphate precipitates, leaving calcium chloride in solution. If any magnesium carbonate is present, the reaction produces insoluble barium carbonate which precipitates, and magnesium chloride remains in solution.

If the scale-forming impurities are present in small quantities, say less than 150 parts per million, then as a rule no purification is attempted; if there are 150 to 300 parts, the plan sometimes adopted is to add the softener indicated by analysis, usually sodium carbonate, to the water reservoir or the tender tanks; if a greater quantity of scale-forming compounds is present, the chemical treatment is almost always carried out in appropriate installations.

The softening of the feed water is adjusted so that about 6 to 8 (German) degrees of hardness are left, as water which is too soft gives trouble by bumping. In districts which take their water from deep lying strata of chalk, the water which has a hardness of 30 degrees or more must be softened so that only 6 to 8 degrees are left.

The water obtained from peaty soil or from deep wells often contains much iron; if this is to be used for boilers, the iron is generally removed by an aeration process. It is true that the iron content hurts the boilers but little, but if too much ferric oxide mud is formed, it may lead to irregular deposits of scale; moreover the water pipes tend to become blocked by the growth of *algæ* and *fungi* (*Leptothrix ochracea* and *Crenothrix polyspora*) to which it serves as a culture-fluid.

In a few cases, the water contains an excessive quantity of common salt, which makes the water bump and foam; crystals of salt become formed at all the cocks and openings, and corrosion results.

Organic impurities, such as finely-divided fibres of peat, and mineral matter in a state of suspension may turn up, during times of floods or heavy rains, in water which is generally good, and may contribute to the formation of scale. Administrations who may suffer from such conditions, try to keep such bodies out as much as possible by special filtering appliances, sand beds or filter presses, before the water enters the suction tubes of the pumps.

2. *Results obtained by the processes of water purification.* — All the administrations state that the results obtained are favourable, and that the use of the softened water is very satisfactory from the economic point of view. Formerly, it frequently happened that tubes began to leak, in consequence of the formation of

much scale; this seldom happens now, as the thickness of the layer of scale has been reduced from 6 to 8 millimetres ($^1/_4$ to $^5/_{16}$ inch) to only 1 or 2 millimetres ($^3/_{64}$ or $^5/_{64}$ inch), and the layers formed are soft and washed away when the boiler is washed out. The Wurtemberg State Railway mentions as a defect of the process, that locomotives which are fed with purified water, particularly those which often serve as reserve, show corrosion at the flue tubes and at the smoke tubes, at the joints where the copper sleeves are brazed on.

As there is less scale, the heat is utilized better, but no administration can give any figures as to the resulting economy in fuel.

The boilers require cleaning less frequently, the smoke tubes remain tight and in good condition for a longer time, the fixe-box tube-plates are less strained by the re-expanding of the tubes. No figures are given as to the saving effected.

There is no doubt that the cost of maintenance is reduced and that the life of the boiler is lengthened by the use of softened water, as the boiler plates and their stays are attacked less, but no administrations can give any figures as to these resultant advantages.

3. *Softening waters the hardness of which is mainly or largely due to calcium or magnesium sulphates, chlorides or nitrates.* — This is effected in the apparatus described under heading 1. The introduction of zinc, to prevent the bad action of chlorides, was unsuccessful. Water containing a larger quantity of chlorides or nitrates is not used as feed water, or is at least avoided as much as possible. In order to prevent violent foaming, the water is not completely softened, but retains a hardness of 6 to 8°. The Baden State Railway at first softened it to 4 German degrees of hardness; but trouble arose, because more water was carried over than the injectors could replace. Should it happen that the water foams over, this is remedied by suitably reducing the amount of sodium carbonate added.

4. *The use of barium hydroxide, barium carbonate or barium aluminate.* — As already stated, barium carbonate is used at a few places, but only exceptionally, as it has been found as a rule that the addition of sodium carbonate and of quickline or of sodium hydroxide purifies hard feed water sufficiently.

5. *Attempts to determine the quantity of sodium salts when there is priming.* — Such attempts have not been made. The Prussian-Hessian State Railway, when treating water having a hardness of 24 German degrees, at first used 220 grams of calcined soda per cubic metre (2·20 lb. per 1,000 English gallons) of water; this was reduced to 135 grams per cubic metre (1·35 lb. per 1,000 English gallons), because there was violent priming and foaming. The Danish State Railway draws attention to the fact that the sodium sulphate content seems to be of as much importance from this point of view as the sodium carbonate content.

6. *Disincrustants placed directly in the boiler.* — Such have been tried by various administrations; in the case of water containing calcium sulphate, sodium carbonate has been placed directly into the tender, and according to the statements of the Baden State Railway, the Dutch State Railway and the St. Gothard Railway, good results have been obtained in this way. The Wurtemberg State Railway is

at present making experiments in this direction. The Bavarian State Railway formerly placed a solution of soda in the boiler, but no longer does so. On the Prussian-Hessian Railway, before the water-purifiers were installed, it was also usual to add soda to the water in the tender, but this method has now become unnecessary.

The Prussian-Hessian State Railway and the Saxon State Railway are at present using, at a few of the locomotive depots, petroleum as an addition to feed-water. In the former case, the petroleum is generally introduced after the boiler has been washed out, 0·5 to 1·5 kilograms (1·102 to 3·306 lb.) of petroleum being added. The latter uses petroleum injectors and adds the petroleum drop by drop to the feed-water.

7. *Tendency of boilers to leak when softened water is used.* — This has not been observed by any of the administrations, unless the alkalinity of the water was increased by an excessive addition of soda. On the contrary, the tendency to leak at the tubes, stays or boiler seams is much reduced if the water is not made too soft, that is if it still has a hardness of about 6 German degrees.

8. *Defects in the interior of the boiler.* — 1° Cracks; 2° Pitting; 3° Grooving; 4° General surface corrosion.

I beg to refer you to the details given in the report.

9. *Statistics of the defects.* — Only a few administrations make sketches, when the boilers undergo heavy repairs, of the defects referred to in question 8, showing the position, extent and depth of those defects. Most of the administrations limit themselves to making notes on the subject in the boiler books or on the repair sheets, and only in exceptional cases of special importance are sketches made or plaster of Paris or lead casts taken.

10. *Prevention of defects when designing the boilers. Breadth of the water-spaces in the fire-box and delivery of the feed-water.* — If the defects are not due to improper treatment or to bad quality of the feed-water, but to the nature of the material, heat expansion, vibrations, special stresses, etc., attempts are made to counteract them by suitable selection and arrangement of stays and stiffeners, by giving the plates a suitable thickness, by allowing a sufficiently-large radius at the bends and corners, by increasing the size of the interspaces in the fire-box tube-plate and by carefully selecting and testing the material most suitable for the part concerned.

It is generally recommended, and especially by the Baden State Railway, that there should be an ample supply of large and accessible openings for cleaning purposes, used for frequent and careful washing out of the boiler. Several railways recommend that the boiler should be properly supported, so that it can expand on the frame without strain, that movable roof stays should be used at the front and back of the fire-box roof and that all fittings inside the boiler should be designed with a view to obstructing the circulation of the water as little as possible, for instance by spacing the smoke tubes further apart. Apart from this, it is the general opinion that the development of the present designs satisfies existing needs, and that the defects referred to in question 8 do not appear so largely as to make any material alterations in the design of boilers necessary.

In order to prevent excessive deposit of scale, such as is observed in the smoke tubes near the spots where the feed-water enters, several administrations do not allow the water to flow straight into the boiler, but put in baffle plates to deflect it and distribute it more uniformly. On several boilers of the Prussian-Hessian State Railway, a definite improvement has been obtained in this way, as far as scale is concerned, but there was greater corrosion in the parts reached by the deflected water. The Bavarian State Railway has obtained good results with these baffle plates. Several administrations also use the appliance for preventing the formation of coherent scale, described by Mr. Karl Gölsdorf in the *Bulletin of the Railway Congress*, 1907, page 976.

11. *Washing out the boilers.* — The best means for preventing damage to boilers which are well designed and properly treated is certainly timely and careful washing out; consequently all the administrations attach particular importance to the proper execution of this work.

Opinions differ as to whether hot or cold washing is preferable. The Alsace-Lorraine Railway, the Baden State Railway, the Bavarian State Railway, the Oldenburg State Railway, the Saxon State Railway, the Prussian-Hessian State Railway, the Dutch Railway Company, the Luxemburg Prinz-Heinrich Railway, and also the Stockholm-Rimbö Railway, pronounce in favour of hot washing out, which they as a rule apply. The Wurtemberg State Railway, the Danish State Railway, the Dutch State Railway, the Norwegian State Railway, the Swedish State Railway, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway use cold water. The last four railways, as well as the Wurtemberg State Railway, go in for hot washing out at a few depots.

12. *Blowing off the boiler under pressure. Blow-off cocks.* — If bad water, containing much scale-forming impurity, is in use, the boilers are blown off at short intervals, of three or more days, at a low pressure, till about one third of the water has escaped through the blow-off cock, which is nearly always placed in the front plate of the fire-box, at the bottom just above the foundation ring; exceptionally a blow-off cock is also placed in one side plate or in each side plate.

When good or properly-purified feed-water is used, this operation is unnecessary, but it is sometimes necessary when the water is softened by the addition of sodium carbonate in the tender, if the deposit is wholly in the form of mud.

13. *Strongly-corrosive water containing mineral acid.* — All the administrations state that such water should not be used.

The Alsace-Lorraine Railway analysed the Moselle water, which was strongly corrosive after softening, and obtained very varying results, which did not make it possible to come to any definite conclusion as to the nature of the chlorine compounds present.

14. *Coating the insides of boilers.* — The different administrations have tried various means in order to present corrosion, but no one has any particular success to report. Painting the inside over with hot tar seems so far to give the best results.

The Bavarian State Railway carefully cleans any parts which are corroded and

coats them with Portland cement; the Alsace-Lorraine Railway tins such places.

15. *Introduction of zinc plates.* — The Alsace-Lorraine Railway alone has tried zinc plates in boilers, in order to counteract the action of the chlorides, but without success.

16. *Stays.* — As a rule, bar copper is used for the stays, which has an ultimate tensile strength of at least 22 kilograms per square millimetre (31,290 lb. per square inch), an elongation of at least 38 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches) and a contraction of area of at least 45 per cent of the original cross-section. In many recent cases, the front and back vertical rows of the stays of large fire-boxes are made of manganese bronze, which is generally specified to have an ultimate tensile strength of 30 kilograms per square millimetre (42,668 lb. per square inch), an elongation of 25 to 30 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches). The manganese content is not to exceed 5 to 7 per cent. The Alsace-Lorraine Railway specifies that this bronze is to contain no tin, while the Danish State Railway specifies that this bronze is to contain 95 per cent of copper, 4·5 per cent of Banca tin and only 0·5 per cent of manganese, and emphasizes that stays with a greater manganese content give bad results. It is stated generally that the manganese bronze is stronger and hence less liable to fracture than copper. As regards burning away, it is stated to be equal to, or slightly less resistant than copper.

The Dutch State Railway and the Danish State Railway, besides manganese bronze, use also Stone metal; the former finds no advantage in doing so.

The Prussian-Hessian State Railway, besides the metals already named, are also using the following experimentally :

a) Durana metal, which has an ultimate tensile strength of 33 kilograms per square millimetre (46,935 lb. per square inch), an elongation of 40 per cent measured on a length of 200 millimetres (7 $^{7}/_{8}$ inches) and a contraction of area of 70 per cent.

b) Ingot iron. The trials so far made would seem to indicate that economic results are not obtained with this material, as this metal is more difficult and consequently more expensive to work than copper, and as the old scrap is worth exceedingly little.

c) Iron stays with a 5-millimetre ($^{3}/_{16}$ inch) hole, supplied by the Ohio Falls Company.

Finally, experiments are being made with hollow-rolled round copper bar, the hole having a diameter of 5 millimetres ($^{3}/_{16}$ inch). As far as present experiments go, the heads wear less than with the ordinary stays. The stays also last longer. They are said to limit to some extent the development of smoke by the air entering through the hole. The trials which have been begun have not yet been completed; as far as they go they show that these stays are somewhat superior to others. Such copper stays are also used, on a more extended scale and with success, by the Dutch Railway Company, the Dutch State Railway and the Swiss Federal Railway.

Much trouble has not been given by the breaking of stays, as everywhere provision is made for the speedy renewal of any broken stays, so that the internal fire-box or the shell can probably not be endangered.

The fractures are in most cases in the side walls within the zone of the fire and near the supports, and also in the upper rows of the side walls and of the back. They are rarer in the neighbourhood of the vertical corners and under the fire arch in the side walls and in the bottom part of the fire-box tube-plate; the Alsace-Lorraine Railway, however, also mentions the latter point as one where fracture frequently takes place.

Flexible stay-bolts are only in use on the Danish State Railway (1). Then also the Norwegian State Railway, in the case of a few locomotives, has put in flexible stays in the last longitudinal rows of the roof stays, about 1 metre (3 ft. 3 3/8 in.) from the tube-plate.

Trouble from stay heads burning away and dropping off has not arisen anywhere.

17. *The use of fire-bricks.* — The Saxon State Railway and the Swedish State Railway are the only ones who have tried fire-brick linings, but have given them up. The former states that the cost of repairing the linings was too high, and that they were, moreover, a source of danger should the walls collapse.

Most of the railways, however, use on their locomotives, to a greater or lesser extent, fire-brick arches of varying sizes and shapes to suit the locomotives in question, the object being to protect the tube-plate and prevent the formation of smoke. Good results are obtained.

(1) Vide *Bulletin of the Railway Congress*, No. of January, 1904, p. 44 ; " Stays of adjustable length for locomotives of the Danish State Railways ", by O. Busse.

Conclusions, question VI, littera C.

The chief boiler defects are :

1° *Cracks* at the top and side bends and in the interspaces of the fire-box tube-plate, at the bends of the fire-box shell and throat plate, at the places where the stays are fixed in the side plates and in the roof, at the riveting of the fire-hole, at the wash-out openings and in the side and roof stays ;

2° *Pitting* in most cases is found in the bottom part of the plates of the barrel, particularly above the boiler supports and near the points at which the feed-water is delivered, to a height of about one third of the diameter of the boiler ; frequently also, in the smoke tubes near the fire-box tube-plate ;

3° *Grooving* is found in the fire-box shell plates immediately above the foundation ring, in the lower part of the smoke-box tube-plate, and at the seams of the barrel ; in this case, the grooves are generally parallel to the caulking line ;

4° *General surface corrosion* is found in the lower half of the barrel, on the outside of the boiler at the wash-out holes and at the seams of the rings of the barrel.

In order to counteract such defects, prevent the deposit of scale and preserve the boiler as much as possible, the best measure is generally considered the purification of the feed-water *before* it is used, the hardness being reduced to 6 or 8 German degrees of hardness.

The different processes of chemical treatment in special plants produce suitable softening and give good economic results. In the case of water which does not contain too much scale-forming content, it suffices if chemicals, especially sodium carbonate, are added to the water in the boiler or in the tender.

In both cases, the quantity of sodium carbonate added must be carefully checked, in order to avoid resulting disadvantages.

The many other remedies for preventing the formation of scale, which have been frequently recommended and tried have not given any good results, except in the case of petroleum.

Devices for separating the scale inside the boilers, such as those of the Rhetian Railway or of the Gölsdorf design, act favourably and appear to indicate a method for the further reduction of the trouble caused by the formation of hard scale.

In order to avoid any disadvantages, both from the economical and from the operating points of view, the boilers must be properly made at the boiler shops and the quality of the metal must be carefully checked; the most important thing then is that the boilers should be properly treated while in use, and above all carefully washed out and cleaned. The expense this involves is much more than counterbalanced by the reduced cost of upkeep and the increased length of life of the boiler.

Washing out with hot water is preferred by the majority of the administrations.

The metal chiefly used for stays is copper; but manganese bronze has also in many cases given good results at points which are not too much exposed to the fire.

All the administrations concerned think that there is no occasion for any material alteration in the present design of boilers, in order to prevent boiler defects.

The President. (In French.) — Gentlement, before calling upon the delegates who wish to discuss littera *C*, I wish, in the name of the bureau, to make two remarks.

This is the first : the reporters who have dealt with littera *A* and littera *C* of question VI are requested to meet after the sectional meeting, with Mr. Gerstner as president, in order to consider whether they are not able to draft joint conclusions, to be submitted to the meeting tomorrow morning.

This is the second : the bureau has been considering whether it is not advisable to subdivide littera *B* which the section is going to discuss tomorrow morning. This littera is certainly one of the most important objects which the 2nd section has to consider; but it really comprises two very distinct subjects, namely that of water-tube boilers and that of superheaters; and it is rather surprising that these two questions are lumped together in one littera. The question of superheating certainly deserves separate considération and your bureau thinks that it would be advisable to treat it separately. (*Approval.*)

Littera *B* will accordingly be subdivided; the reporters who will speak tomorrow are requested to distinguish between the two questions in their conclusions — as indeed most of them have done in their reports — and littera *B*-1° and littera *B*-2° will be discussed separately.

Does any delegate wish to address the meeting in order to supplement the information given to us by the reporters, relating to littera *A* and to littera *C* ?

Mr. Archbutt. — In Mr. Antochine's report, the calcium oxide, the magnesium oxide, the carbonic acid, the sulphuric acid and the chlorine shown in the table on page 275 of the English edition [1] are given in grammes per litre. In order to avoid any misunderstanding, a note to this effect should by added to the table, as question 13 asks for parts per 100,000.

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[1] See also *Bulletin of the International Railway Congress*, No. 5, May 1910, p. 1793.

The tinning of boilers, mentioned by Mr. Antochine and also by Mr. Steinbiss, does not seem likely to form an efficient protection against corrosion, because tin is electronegative as compared with iron. The same remark applies to filling up cracks or pitting inside the boiler by means of tin or of babbit. Would this not rather tend to increase the corrosion? How is the tinning done? What flux is used?

In Mr. Papp's report, the statement made on page 221 (1) that no company is able to estimate the economy which results from the use of purified water, a statement which is also to be found in other reports, is a subject of regret. If one could know these figures, water purification would probably be used on a much larger scale. The use of lime and of barium carbonate on the Austrian State railways is interesting. It would by useful to have figures showing the real cost, as compared with that of barium hydrate, and to have details about the process, for it is one rarely used.

On page 222, question 5, the reporter states that he has observed, in the case of the locomotives of the Hungarian State Railway, that sodium salts only remain dissolved in small quantity in boilers in which scale has been depositing for a long time. Would Mr. Papp kindly explain to us the meaning of this phrase? I do not see how scale can affect the solubility of the sodium salts.

As regards the use of cylinder oil as disincrustant on the Aussig-Teplitz Railway, is not overheating to be feared?

The water analysis given by the Austrian Northwestern Railway (p. 230) is remarkable for the large amount of potash contained. In my opinion, it would not be possible to concentrate this water much, or else priming would result.

The answers to question 14 show that no protective coating on the inside surfaces of the boilers has been found useful by the different railways, as a means for preventing corrosion. Similarly protective linings for the fire-boxes have given poor results when the fuel used was coal. The difficulty evidently arises from the fact that the alkaline constituents of the coal ash rapidly attack the silicates on the surface of the refractory bricks.

Mr. Nadal quotes in his report (p. 17) (1) the figures given by the Bône-Guelma line, concerning the economies resulting from the purification of the water; they are as follows :

A saving of 4 per cent in the coal consumption;

The mileage of the locomotives between two consecutive washings is doubled;

The life of the tubes is doubled;

The cost of upkeep of the boilers is materially reduced.

This information is very valuable; it is a pity that similar information has not been supplied by other administrations.

I have been struck by the extensive use made of disincrustants, particularly of barium aluminate and of quebracho, in the boilers of the locomotives on the French railways. On the Midland Railway, we have not obtained good results

(1) See also *Bulletin of the International Railway Congress*, No. 4, April 1910, p. 1477.

(1) See also *Bulletin of the International Railway Congress*, No. 7, July 1909, p. 602.

with barium aluminate, and the same appears to have been the case on the Prince Henri Railway, in Luxemburg. We found that quebracho was one of the best disincrustants in the case of stationary boilers. But in that of locomotive boilers, these two disincrustants produced leakage in the tubes. The Great Northern Railway, in England, has obtained very good results with barium aluminate.

One would like to have further information about the graphite and mineral paint used in boilers by the French Eastern Railway, and about the cement used by the Italian State Railway; if the cement only lasts for a few months its use in locomotive boilers is limited. Nevertheless it is of interest to hear that it is found to be useful.

The experience of the Danish State Railway, reported by Mr. Steinbiss, that sodium sulphate appears to produce spitting and priming as readily as sodium carbonate, is in contradiction with what has been observed on several English railways.

The President. (In French.) — Mr. Archbutt's remarks will be translated, and communicated to the reporters who have been questioned by him.

Subject to the reservation that supplementary statements can still be made tomorrow, it is understood that at the termination of the meeting the different reporters who have dealt with littera *A* and littera *C* of question VI will meet, with Mr. Gerstner as president, in order to draw up joint conclusions.

If nobody else wishes to address the meeting, we will adjourn till tomorrow.

Meeting held on 9 July 1910 (morning).

MR. ERNEST GERARD, VICE-PRESIDENT IN THE CHAIR.

The President. (In French.) — Gentlemen, we will now begin the discussion of littera *B* of question VI. I will request the reporters to be as brief as possible and to limit their statements to the principles set forth in their report, so that they may quickly reach the conclusions they bring forward. We wish very soon to reach the discussion on the important question of superheating, which forms the second section of littera *B*, and it is important that the reporters should limit their remarks.

Mr. Dassesse, *reporter for Belgium, France, Italy, Spain and Portugal.* (In French.) — The application of high superheat to locomotives has been considerably extended during the last few years. The superheater in favour is the Schmidt superheater, which is located in the smoke tubes. In Belgium, in 1903, there were three locomotives with superheater; at present there are nearly five hundred. In 1909, the Spanish Northern Railway had equipped sixty-nine locomotives in this way, the Italian State Railway

forty-eight, and the Milan Northern thirty. All the French companies have also applied Schmidt superheaters extensively, and most of them have even combined superheating with compounding. The superheated-steam type with four equal cylinders, extensively used in Belgium, has recently been tried on a *Pacific* locomotive by the Paris-Lyons-Mediterranean Railway and has given every satisfaction, as I show later on. The Italian State is at present having six *Pacific* locomotives built, with four equal cylinders. The Belgian railways have by now had long experience of the use of superheated steam; and this experience enables me to draw the attention of the Congress to several details of design which will save those less experienced some trouble at the start. I will give as short a summary of them as possible.

The superheated-steam collector must be connected to the tube-plate by means of a joint with a spherical-face ring. The mothod of fixing the large tubes in the fire-box tube-plate which has given the best result is as follows : the fire-box end of the tube is contracted and has five grooves made in it, 2 millimetres ($^3/_{32}$ inch) wide by 0·5 millimetre ($^1/_{32}$ inch) deep, and is expanded in the tube-plate and beaded over cold.

It may also be remarked that the superheater flap or damper of the locomotives of the Belgian State Railway is in one single piece, which opens by swinging down. It can move down to a little below the horizontal plane, so as not to interfere with the draught in the lower tubes and so as to facilitate the collection of the cinders in the smoke-box. The hot gases from the large tubes flow in a direct line to the chimney without deviation and then turn upwards as in the ordinary system, and the result is that there is no accumulation of cinders in the large tubes containing the superheater elements.

In order to prevent the fracture of the small superheater tubes at the thread entering the steel connectors, the threaded part in the latter is contined by a smooth part into which the tube enters, so that the thread is protected against the action of the hot gases, from cinders and from damp, which might produce corrosion.

The pyrometer which has given results most concordant with those of the thermometer used for checking it, is the Fournier saturated-steam tension pyrometer, provided that the pocket containing the liquid is entirely surrounded by superheated steam.

The pistons must have a play of 3 millimetres ($^1/_8$ inch) in the cylinder; if the play is less, trouble is likely to result; the piston may seize and the cylinder may even become broken. The rods are ground true so as to reduce their friction in the packing.

The Belgian State Railway tried, in the case of two locomotives, valves with solid non-elastic rings. After running 60,632 kilometres (37,676 miles), it was found, during a stationary trial, that when the valves in their mean position were subjected to the action of steam at a pressure of 8 atmospheres (113·78 lb. per square inch) there was a loss of steam of 1,465 kilograms (3,230 lb.) per hour.

Apart from this single case of a valve with a solid ring, all the locomotives of the Belgian State Railway are fitted with the valves with three rings, two of which are cut and are thin and elastic. With one

ring, whether solid, the driver cannot continue his journey without risk of seizing in the cold part of the jacket; this is not the case with multiple and thin rings which contract as they enter the zone which is less expanded. On the Belgian State Railway, the instructions given to the staff driving the superheated-steam locomotives, do not contain any special proviso as regards any change in the stroke while running or at the moment the regulator is closed, and the considerable experience already obtained with locomotives using superheated steam has not shown that any trouble results.

The tightness of our valves with thin and elastic rings has been checked and found perfect after running 47,000 kilometres (29,200 miles); the only thing observed was a wear of 0·4 millimetre ($^1/_{64}$ inch) in the liner, and the springing open of the rings made up for this.

As regards packing, it is necessary that there should be a free access of the outer air to that part of the gland where the white-metal rings are. Moreover, in order that they should give to the movements of the rods while remaining tight, it is necessary for the seats of the spherical rings to have a common centre.

Besides the atmospheric valves which are fixed to every valve chest, the bottom and top are fitted with a safety valve whose diameter was increased from 40 to 60 and finally to 100 millimetres (from 1 $^9/_{16}$ to 2 $^3/_8$ and finally to 3 $^{15}/_{16}$ inches) to provide for possible water-hammer action. This has been known to take place when the water-level was high and the surface of evaporation was consequently reduced. The pyrometer drops quickly to 200° C. (392° Fahr.). During long stops, the separate superheater becomes cooled and when steam is admitted it condenses in the tubes. But water-hammer action is especially to be feared when the valves for admitting the steam are leaky. The steam then condenses during stops in the cooled superheater, and at starting the accumulated water is sent with a rush into the cylinders.

All the locomotives are at present fitted with pipes connecting the two sides of the piston. They are only used when running down long gradients. The resulting increase in the clearance space causes, it is true, a slight waste of steam, but prevents the formation of any diagram loop.

The increased volume which is produced by superheating the steam as well as the partial or total elimination of condensation in the pipes and cylinders necessarily involves an increase in the capacity of the cylinders. In the case of the compound locomotives, only the diameter of the high-pressure cylinder is increased and sometimes flat slide valves are even retained for the low pressure. As a greater volume of steam, less liable to condensation, is available, it is possible to reduce the working pressure, except in the case of compounds in which a high initial pressure is indispensable.

As the locomotives using superheated steam have stronger cylinders, it is necessary, when less force is required, to keep the cut-off as it is and to manipulate the regulator so as to maintain smooth running. If this is done, the final pressure of the steam is a little greater than with earlier cut-off and full pressure, but the greater superheat of the steam expanded at the regulator ensures the more complete elimination of the condensations during

the cycle and makes up for the loss resulting from shorter expansion. For instance, the temperature of saturated steam at a pressure of 14 kilograms per square centimetre (199·12 lb. per square inch) is 197° C. (387° Fahr.); if this temperature is increased to 350° (662° Fahr.), the superheat will be 350° — 197° = 153° C. (275° Fahr.) That steam can accordingly have its temperature reduced 153° C. (275° Fahr.) without any condensation resulting. If, the steam being produced at a pressure of 14 kilograms per square centimetre (199·12 lb. per square inch), it is only utilized in the cylinders at a pressure of 9 kilograms per square centimetre (128 lb. per square inch), the temperature remaining the same, the superheat will be 350° — 179° = 171° C. (308° Fahr.).

A superheated-steam locomotive is about 1,900 kilograms (4,200 lb.) heavier than a saturated-steam locomotive of the same type, with flat slide valve. The price paid by the Belgian State Railway for equipping such a locomotive with a superheater and with piston valves including the mechanical lubrication and the pyrometer, varies between 4,000 and 5,000 francs (between £160 and £200), according to the state of the market and the type of the locomotive. To this the royalty has to be added. The total extra expense is only a slight addition to the price.

Lighting up, in the case of superheated-steam locomotives, is done with the damper closed; the indirect heating surface of the locomotives using superheated steam, already less than that of similar locomotives using saturated steam, is reduced still further by the internal surface of the large tubes. The superheated-steam locomotives accordingly take about 15 per cent longer than the ordinary locomotives before they are in full steam; the same applies to the coal consumption which is increased by 8 to 10 per cent each time the fires are started.

Trials have shown that it is quite unnecessary, to say the least of it, to fit superheaters to locomotives used for hauling light trains which stop frequently. Superheating is above all advisable when there are long runs without stops, and it is the more advantageous, the heavier the work (whether load or speed) the locomotive has to do.

Lines on the flat on which the work the locomotives have to do remains practically constant and uninterrupted are very suitable for superheated-steam locomotives.

Lines with long and steep gradients are also suitable for superheated-steam locomotives. The same applies to lines with saw-teeth gradients, as soon as the uphill sections are of a certain length.

The additional power obtained by superheating is not available at the start; it is obtained only after running a certain distance, varying with the nature of the train and the profile of the line. Sometimes 8 to 10 kilometres (5 to 6·2 miles) are required in order to attain 300° C. (572° Fahr.).

In order to ascertain whether owing to the reduced heating surface the superheated-steam locomotive is not at the start inferior to the saturated-steam locomotive, the Belgian State Railway made the following trials :

Superheated-steam locomotive, type 18. — Weight of train, 250 tons. Time required for running 9,400 metres

(5·84 miles), 8 minutes 28·4 seconds; speed attained, 87 kilometres (54 miles) per hour.

Saturated-steam locomotive, type 18. — Weight of train, 206 tons. Time required for running 9,400 metres (5·84 miles) 8 minutes 54 seconds; speed attained, 85 kilometres (52·8 miles) per hour.

The great fluidity of superheated steam makes it undoubtedly superior to saturated steam, particularly at high speeds.

Trials have recently been made on the Belgian State Railway in order to examine the variations in the tractive effort of a superheated-steam locomotive at different speeds, for a given cut-off. The trials were made with an express locomotive with four equal cylinders. The train hauled weighed 332 tons, the cut-off was set at 26 per cent and the regulator was half open.

From 103 to 123 kilometres (64 to 76·5 miles) per hour, the variation is only 200 kilograms (440 lb.), or 5 per cent; at 123 kilometres (76·5 miles) per hour a tractive effort of 3,825 kilograms (8,433 lb.) is still developed, and the power obtained amounts to 1,750 horse-power.

As regards results obtained with superheat, a distinction must be drawn between trials proper and current practice. In trials, the superheating applied to certain two-cylinder non-compounds on the Belgian State Railway resulted in savings of up to 29·64 per cent of coal and 28·67 per cent of water. On the Milan Northern, the tractive effort of certain non-compounds using superheated steam was increased by 25 per cent when the coal consumption was increased 10 per cent, the water consumption remaining practically unchanged.

The combination of superheating and compounding increased the power of the four-cylinder compounds, with three coupled axles, of the French Western Railway by 14 to 15 per cent. The Paris-Lyons-Mediterranean Railway made trials with two high-speed locomotives of the *2600* type (with three coupled axles and bogies), one being a compound with Schmidt superheater, working pressure 16 kilograms per square centimetre (227·57 lb. per square inch), the other a compound, without superheater, also with a working pressure of 16 kilograms per square centimetre (227·57 lb. per square inch). The trials were made between Paris, La Roche and Dijon, with special trains; the superheated-steam locomotive showed an economy of 13·25 per cent of coal and of 22·76 per cent of water, per indicated horse-power; and of 17·57 per cent of coal and of 26·37 per cent of water, per horse-power measured at the drawbar. On the Italian State Railway, a difference of 15 per cent was similarly found between a superheated-steam compound of the *Prairie* type and a compound of the same type, but without superheater. Then also in 1910 the Paris-Lyons-Mediterranean Railway put in service two *Pacific* locomotives, one being a saturated-steam compound, working pressure 16 kilograms per squere centimetre (227·57 lb. per square inch), and the other a superheated-steam locomotive, with four equal cylinders, working pressure 12 kilograms per square centimetre (170·67 lb. per square inch). These two locomotives were otherwise of the same design. Each of them hauled eight special trial trains between La Roche and Blaisy-Bas. The loads varied from

272 to 450 tons. A dynamometer car was used and indicator diagrams were taken; the conclusions drawn from these trials were that the superheated steam locomotive showed an economy of 13·07 per cent of coal and of 15·08 per cent of water per indicated horse-power, and of 16·53 per cent of coal and of 18·83 per cent of water per horse-power measured at the drawbar.

On the Belgian State Railway, a series of comparative trials were made with a superheated-steam locomotive with three coupled axles and four equal cylinders, and an *Atlantic* compound without superheater. These two locomotives are practically of the same weight and have the same grate; their chief dimensions are also very much the same. The superheated-steam locomotive, as compared with the compound, showed a saving of 12·3 per cent of briquettes and of 9 per cent of water, per indicated horse-power; then also the mean speed of the superheated-steam locomotive was 5 per cent higher than that of the compound.

Comparing these figures with those previously obtained with locomotives which were in good condition, it follows that four-cylinder compound locomotives using superheated steam and four-cylinder non-compound locomotives using superheated steam are about equally efficient. These results may however, after a certain time, become modified in favour of the compounds, any leakage past the piston and the valves being utilized in the low-pressure cylinders of the compounds and lost in the non-compounds.

I will however add, as regards more specially the Belgian State Railway, that the piston valves with their rings, which are used, have proved satisfactory as regards leakage, which has been found to be entirely absent after running 47,000 kilometres (29,200 miles).

The trials have also demonstrated the superiority of the locomotive with four equal cylinders in the following respects: 1° it is easier to drive; one single mechanism operates the four valves and at starting the full pressure is at once applied to the four pistons without any necessity for operating a special starting valve; 2° greater stability at high speeds.

The results obtained in actual practice generally confirm those obtained in the trials. To mention one example, sixteen superheated-steam locomotives, at Antwerp, were used during 1907 and 1908 for the same work as thirty-eight locomotives of the same type and age, but using saturated steam. The saving of fuel of the superheated-steam locomotives was 18·92 per cent in 1907 and 16·26 per cent in 1908.

In Italy, the 640 series of locomotives (1-3-0, non-compounds using superheated steam) as compared with the 630 series (1-3-0 compounds, two cylinders), for the period of one year, showed a saving of 10 per cent, as recorded in the reports which Mr. Greppi has given me.

On the Paris-Lyons-Mediterranean Railway, the figure recorded was 11·5 per cent after making comparisons, for nine months, between compound locomotives with and without superheaters, which during the trials had shown 4·5 per cent in the case of goods locomotives with three coupled axles and wheels 1·30 metres (4 ft. 3 $^{3}/_{16}$ in.) in diameter. On the other hand, ten locomotives of the 4,500 series (compounds, four cylinders, four coupled axles, wheels 1·30 metres in

diameter, working pressure 15 kilograms per square centimetre (213·34 lb. per square inch), type 0-4-0, fitted with Schmidt superheater) were compared in the course of the ordinary service with ten locomotives of the same series but without superheaters; five of these locomotives were at first attached to the Dijon depot, then to the Ambérieu depot, and the five others to the Roanne depot. At Dijon (duration of experiment, five months), the superheated-steam locomotives showed an inferiority of 3 per cent, at Ambérieu of 5 per cent, and at Roanne of 11 per cent. These locomotives were fitted with valves having solid rings which are going to be replaced by others of the same kind as those used on the *Pacific* and *2600* locomotives, in order to see whether better results will not then be obtained.

The additional power obtained with the superheated-steam locomotives is represented by an increase in the maximum load; in Belgium, this increase has been 10 to 15 per cent in the case of passenger locomotives and 15 per cent in that of goods locomotives; on the French Western, it has varied between 10 and 15 per cent according to train. In Italy, the locomotives of the 640 series haul 10 per cent more than the similar two-cylinder compounds of the 630 series.

Upkeep and repair of superheated-steam locomotives. — As regards the superheater proper, it has to be noted that quite a number of the small superheater tubes became broken at the thread entering the steel bend-connectors. In the method adopted in order to prevent such fracture, the thread does not begin flush with the surface of the connector, but only 5 millimetres ($^3/_{16}$ inch) further in. Brazed joints, shaped like a U pointed, are also being tried for the same purpose. This has the advantage of not reducing the cross-section available for the passage of the gases.

During the five years that superheating has been in use, only small superheater tubes have had to be taken out owing to wear or cracks.

Scale deposited more or less quickly in the superheater elements; it was observed, in the case of locomotives which had been in use for three years, that the scale extended to about 2·50 metres (8 ft. 2 in.) from the saturated-steam collector; the scale had a thickness of 4 to 6 millimetres ($^3/_{16}$ to $^1/_4$ inch) near the ends and then decreased gradually.

The superheater remains tight; the joints between the elements and the collector hold well and it is seldom necessary to take out the superheater tubes.

At first it was necessary to remake some of the joints between the collector and the tube-plate. Care must be taken during the erection that the collector is well supported on the two angle-irons riveted to the smoke-box, and a joint made with a spherical-face ring is used, so as to ensure some amount of mobility to the whole installation.

The fixing of the elements in the large superheater tubes has produced, at the points of contact, perforations which were observed on locomotives which had been in use for four years; in other cases large tubes, principally of the bottom row, were replaced after having been expanded several times. The number of large tubes replaced up to 1 April 1909 amounts to 98. The method of fixing, shown in figure 2 of

my report, has been adopted in order to obtain better tightness, and this effected some improvement.

In the case of a few locomotives, it was observed that the fire-box tube-plate had become very slightly deformed, between the bottom row of the large tubes and the top row of the small tubes. That part of the plate which is between the two rows had become bent towards the back : the deformation amounted to from 2 to 4 millimetres ($^3/_{32}$ to $^3/_{16}$ inch) at the middle and tapered off to nothing towards either side.

On 31 December 1906, the stock included 56 superheated-steam locomotives. If we deduct the locomotives which began running in December, we have 47 superheated-steam locomotives used in the year 1906, which ran altogether 1,038,519 kilometres (645,317 miles). The work of upkeep and repair resulting from the superheating and carried out at the sheds, on the superheater, the damper, the pistons, the cylinders, the valve gear and the stuffing boxes resulted for all these 47 locomotives in a total laying-up time of 372 days, or one day per 2,800 kilometres (1,740 miles). Of these 372 days, 228 were devoted to the piston-rod stuffing boxes. In 1907, these same 47 locomotives ran 1,703,964 kilometres (1,058,813 miles), and the laying-up time (resulting from the superheating) was 522 days, or one day per 3,450 kilometres (2,144 miles) run. Piston-rod stuffing boxes again account for the greater part, namely 301 days.

During the first six months of 1908, the laying-up resulting from the superheating, heating, was 251 days for the 47 locomotives which we are considering, 115 days of them being due to stuffing boxes. The improvement is thus evident.

The Pielock superheater has received few applications. The same applies to the Lentz valve gear. The Pielock superheater is more of the nature of a reheater which has given, on the Paris-Lyons-Mediterranean Railway in particular, a saving of 10 to 12 per cent of coal and of 12 to 15 per cent of water.

The expansion of the tubes in order to make the superheater tight gives rise to difficulties. Cracks have been found in the smoke tubes in the parts going through the superheater and surrounded by the superheated steam.

On the Paris-Lyons-Miditerranean Railway there is also a locomotive equipped with a Notkin superheater, which is being tried.

I now come to the question of water-tube boilers.

The President. (In French.) — Would it not be preferable to keep the two questions separate?

Mr. Gerstner. (In French.) — I think it would be better for Mr. Dassesse to deal with the question of water-tube boilers as well. Several reporters — I am one of them — have dealt rather at length with this question, while others have not considered it.

Mr. Dassesse. (In French.) — I will only say a few words about this subject.

In France, the Paris-Lyons-Mediterranean Railway is trying two Brotan boilers on non-compounds, working pressure 11 kilograms per square centimetre (156·45 lb. per square inch); the Midi Railway is also trying two Brotan

boilers, but on compounds having a working pressure of 16 kilograms per square centimetre (227·57 lb. per square inch), the object being to avoid the frequent renewal of the stays and the repairs of the tube-plates which crack at the upper corners, while at the same time obtaining a better utilization of the hot gases and a better circulation of the water; but the trial has as yet been too short to make it possible to draw any conclusion as to the advantages and disadvantages of such boilers as compared with the ordinary boilers.

The Belgian State Railway has also had two Brotan boilers in use for one or two years. The locomotives with these boilers consume 2 kilograms of coal less, per kilometre (7·10 lb. per mile), than other similar locomotives; but this may be due to the fact that the Brotan locomotives are quite new and have a higher working pressure. They have however this disadvantage : the clinker becomes stuck to the bricks at the bottom of the fire-box and it becomes very difficult to open the damper in order to clean the fire.

These locomotives have not given rise to any irregularity in the running of the trains; there has been neither delay, nor break-down, nor has bad weather had any effect on the loads hauled. They have much flexibility.

The Paris-Lyons-Mediterranean Railway is also trying a boiler invented by Mr. Robert, the chief engineer of its Algerian lines, but we do not yet know the results of the trials made.

The Italian State Railway in 1908 put in service some locomotives with Cormark water-tube boilers. Their use has not given rise to any difficulty, but the administration of the railway is not yet able to supply any definite information.

The French Northern Railway has made a very interesting trial with an express compound locomotive with two coupled axles and two bogies, designed by the late Mr. du Bousquet, jointly with Mr. Koechlin, the chief engineer of that railway. This locomotive was on view at the Brussels exhibition and I will not describe it. I will only mention that its working pressure is 18 kilograms per square centimetre (256 lb. per square inch), that its fire-box heating surface is 96 square metres (1,033·37 square feet), and that it has outer tubes of 30/35 millimetres ($1\ ^3/_{16}/1\ ^3/_8$ inches) and inner tubes of 25/35 millimetres ($1/1\ ^3/_8$ inches).

According to information published in the *Revue générale des chemins de fer* for June 1910, this locomotive had run 32,800 kilometres (20,400 miles) when its boiler behaved excellently from every point of view; no crack had formed in the fire-box tube-plate. Its steam production was great. A train weighing 272 tons was hauled up the Survilliers gradient (5 per mil) at a speed of 100 kilometres (62·1 miles) per hour and on the flat, between Compiègne and Tergnier, the train ran at 120 kilometres (74·5 miles) per hour with ease.

I still have a few words to say about feed-water heaters, a question of very minor importance.

The French Northern Railway and the Paris-Lyons-Miditerranean Railway are trying the Caille-Potonié system. The French Northern is trying it on a goods locomotive with four coupled axles and outside cylinders, and on a suburban

locomotive with two coupled axles and two bogies.

The results obtained with these two locomotives have up to the present been quite satisfactory. The pump supplies enough water for consumption in all cases ; the average temperature of the heated water before it enters the boiler varies between 85 and 90° C. (between 185 and 194° Fahr.)

From the point of view of economy, the consumption of water is the same as in the case of a locomotive of the same series fed by an injector ; and the saving of fuel has been 0·750 kilogram (2 661 lb. per mile) as compared with similar locomotives fed by an injector.

It now only remains for me to read my proposed conclusions.

The President. (In French.) — Do your conclusions differ from those which have been published, and is it necessary to read them ?

Mr. Dassesse. (In French.) — There are some small differences between my published conclusions and my new conclusions : I will limit myself to pointing them out.

In my first conclusions I wish to introduce the following clause : " Superheating is not to be recommended in the case of locomotives used for hauling light trains which stop frequently."

I propose to modify clause 10 as follows : " By equiping a compound locomotive with a superheater, its efficiency is increased by about 15 per cent."

I wish to modify clause 12 as follows : " It would appear from the comparison of the figures given above, obtained with locomotives in good condition, that the four-cylinder express compound locomotive using superheated steam does not show any marked advantage over the similar four-cylinder single-expansion locomotive using superheated steam. Nevertheless, if very careful maintenance is lacking, the advantage in favour of the compound locomotive may perhaps become more marked after a certain period of service, any leakage past the valves and the pistons being utilizable in the low-pressure cylinders in the case of the compound locomotive, and lost in that of single-expansion locomotives. "

Mr. Gerstner. (In French.) — I think we must not lose time in discussing the modifications to be introduced in the conclusions of one single reporter. It is customary, when there are several reporters, to try to draft joint conclusions, and it has always been understood that we should proceed in this way. It would therefore be time lost if we now devoted it to the discussion of one special set of conclusions.

Mr. Dassesse. (In French.) — Those conclusions can be discussed by the reporters, as has been done in the other cases.

The President. (In French.) — I think however that M. Dassessé does well in mentioning the modifications he proposes to introduce in his conclusions, for during the general discussion objections might be brought forward which these modifications remove.

Mr. Gerstner. (In French.) — Mr. Dassesse has certainly done well, but it is not necessary for the modifications mentioned to appear in the minutes.

Mr. Fowler, *reporter for Great Britain.* — With superheated locomotives, we generally obtain an economy of 12 to 15 per cent.

They have the disadvantage of adding about 2 tons to the weight, which increase may be a disadvantage from a permanent way stand point. Trials have been undertaken recently for heating the feed water by means of a portion of the exhaust steam passed into the tender.

Mr. Gerstner, *reporter for Austria, Hungary, Rumania, Turkey, Servia and Bulgaria.* (In German.) — In the first place, I have to speak to you, taking the point of view of the countries to which my report relates, about water-tube boilers for locomotives. In Austria, we find only one type of them, namely the Brotan boiler, which is a combination of the ordinary boiler with smoke tubes and the water-tube boiler. In fact the barrel is a boiler with smoke tubes, the rest being a boiler with water-tubes.

You know all the advantages of the Brotan boiler. It makes it possible to eliminate the use of copper, to construct very large fire-boxes, to have grates of large area, while avoiding the disadvantages of ordinary fire-boxes made of copper and of fire-boxes made of steel. The important feature of the Brotan boiler is the very free circulation of the water, which increases the steam production. On the other hand the Brotan boiler has the disadvantage that this great steam production results in steam which is very saturated. The steam can however be dried by using a superheater. That is what is done on the Austrian railways.

The results from the point of view of steam production are accordingly very good. As regards maintenance, they are still a little doubtful, as the time during which these boilers have been in regular use is still too short for definite results.

We now have to examine other improvements which have been made in connexion with the steam. The most important is certainly superheating, that is to say all devices for producing superheated steam or at least dry steam.

As you all know, there are three types of superheaters. In the first place, there are superheaters placed in the smoke-box; this group includes the superheaters of the Hannoversche Lokomotivfabrik, of Ranafier, of Hagans, of Löw, and of the first Schmidt pattern. The second group includes the superheaters placed in the barrel, namely those of Clench, of the Austrian railways, of Pielock and of Slucki. Finally, the third group includes the superheaters placed in the tubes themselves and using to some extent the direct heat of the gases produced by combustion; such are the Vaughan and Notkin superheaters, the American Schenectady type, the Cockerill type, and the Schmidt superheater, the use of which is becoming more and more general.

Three types of superheaters are at present in use in Austria : the Clench and Austrian railway pattern, the Pielock and the Schmidt in the tubes.

The Clench apparatus used on the Austrian State Railway consists of a third tube-plate placed about 1,500 millimetres (4 ft. 11 in.) from the smoke-box; the tubes pass through this space in which the steam is superheated by the hot gases flowing

through the tubes. This system is strictly speaking a drying system and not a superheating system proper, as the difference of temperature barely attains 45 to 50° C. (72 to 90° Fahr.) The small amount of superheat makes it possible to retain the ordinary chest and the ordinary stuffing-box, and piston valves must not be necessarily used. That is however an advantage which I do not consider very important, for I believe that piston valves can be used for both saturated-steam and superheated-steam locomotives equally well.

A serious disadvantage of the system is the difficulty of making sure that there is no leakage between the smoke tubes and the intermediate tube-plate. There is also a fear that the tubes may become oxidized in the drying chamber, and in fact they have become so oxidized. There is considerable difficulty in putting in the tubes and getting them tight, and taking out the tubes nearly always involves thier complete destruction. The Pielock superheater consists of a cubical chamber placed in the middle of the boiler, through which the smoke tubes pass; only a few such superheaters are in use.

The superheater which we chiefly use in Austria is the Schmidt superheater; I need not give details. I will merely state that this superheater is used on 73 locomotives of the administration to which I have the honour to belong, and that altogether 162 locomotives so equipped are in use; it will be fitted to 161 locomotives, which will make a total of 323 locomotives.

As you know, the amount of superheat obtained, varies with the intensity of the work of the locomotive. When little work is done, there is no superheating proper; with heavy and continuous work, the temperature attained is 300 to 320° C. (572 to 608° Fahr.) We use the pyrometer in order to measure the amount of superheat; this instrument however frequently requires repair. The water consumption becomes smaller when the superheat is increased; the saving in fuel is not proportionate to the superheat, but lags a little behind, probably because the coal is a little less efficient when the boiler is required to give more power. In my opinion, one of the greatest advantages of superheating consists in the possibility of giving up the high pressures hitherto necessary, and of returning to normal and reasonable pressures; we have come back to 12 atmospheres (170·67 lb. per square inch) for locomotives of the express type. Everybody knows that lower pressures make it easier to maintain the boilers and we have in fact obtained excellent results from this point of view. The saving in fuel which we have recorded is less than that mentioned by Mr. Dassesse; it must however be mentioned that the distances and loads cannot altogether be compared with the figures given by our Belgian, French and Italian colleagues. We will add that with us the saving in water is equally great, but that the saving in fuel hardly exceeds 10 per cent. We can however for the moment be satisfied with this; for if the superheated-steam locomotives cost a little more in the way of capital outlay and cost of lubrication, we have, on the other hand, the saving in maintenance, in water and in fuel.

As regards maintenance, very nearly every thing that I could tell you has been said by Mr. Dassesse. From that point of view we have had no difficulty, not

even that mentioned by Mr. Dassesse, in connection with the tube-plate. This result is perhaps due to our washing-out system; for we never wash out our locomotives with cold water, we always use hot water. Perhaps that is the cause of the slight difference of opinion, which exists between Mr. Dassesse and me.

We have had hardly any trouble with the stuffing-boxes. At first we used those of the Schmidt pattern, and had some little trouble; but this we overcame by using another alloy; we took a rather softer metal, containing a little more lead. Under these conditions, we have had no trouble with the superheating.

The only thing I can draw attention to, which Dassesse has already mentioned, is the absolute necessity of cleaning the tubes, as soon as the locomotive returns to the depot, by means of a steam-jet or an aspirator, and to grind the rods very smooth and true. Unless the rods are ground true, it is not possible to preserve the packing.

As regards the rest, I will merely request you, gentlemen, to read the appendix following my report, showing the state of maintenance of the most important details of the superheated-steam locomotives, with Schmidt smoke-tube superheater, on the lines of the former Austro-Hungarian State Railway Company.

I will sum up by stating that the superheated-steam locomotive is more economic than the saturated-steam locomotive.

The question of feed-water heaters does not exist in the countries my report deals with; I can only mention one single modern application, namely a filling valve of a suction injector on the Austrian State Railway.

Like Mr. Dassesse, I will abstain from reading out my conclusions which I will request you to read in my report.

The President. (In French.) — In the name of the section, I thank Mr. Gerstner for his very clear and concise summary.

Mr. Noltein, *reporter for Russia.* (In German.) — Gentlemen, I will not read my report to you, for I assume that those among you who are interested in these questions, have looked into it. But seeing our rapid rate of progress, a year — a year has elapsed since I wrote my report — is a time during which there are many changes. Hence you will allow me to bring before you the information I have collected since the completion of my report.

If you ask me today whether I have arrived at the same conclusions, I will answer both yes and no. No, because after the good results which we had obtained when I drew up my report, we obtained others which were very unfavourable; yes, because we have succeeded in elucidating the reasons of these bad results, and because the measures taken have led to considerable improvement.

In the first place I will mention the only type of water-tube boiler which we use, namely the Brotan boiler. I said that with proper management, it worked reliably and economically. You will also find certain theoretical considerations set forth in my report, which show that the Brotan boiler should give a certain saving in fuel, amounting, according to the calculations, to from 3 to 5 per cent. If any greater saving has really been attained, the difference is due no doubt to special conditions. The results of the trial runs

made in order to ascertain the cause of these facts prove that the saving effected by the Brotan boiler, when the engine is working, agree very accurately with the theoretical figure. Any greater economies shown in the statistics are to be attributed to other reasons, more or less foreign to the actual working to the boiler while running.

In the first place it has to be mentioned that this boiler is more economical when lighting up and also whenever but little steam is required, that is to say whenever the locomotive hauling the train is stopped, or in a general way, is doing less work. That is the cause of the greater economies observed in practice. But in addition, the trial runs have shown that it is difficult to eliminate one factor which is of paramount importance as regards consumption of fuel, particularly if small coal is used. In that case, differences always arise owing to the greater or lesser quantities of unburnt coal carried over, and it is hardly possible to calcutate the effect produced by the position of the regulator. The great saving observed with the Brotan boilers on our lines is above all due to their economical working when the regulator is closed or when but little steam is generated. Moreover, these locomotives, as being trial locomotives, were in the charge of better drivers, who were able to obtain considerable savings even when the regulator was opened to a considerable extent; but in all cases the Brotan boiler made it possible to save a considerable amount of fuel when the standing still, when shunting operations were carried out and when a very reduced amount of work was being done.

We are far from thinking that a Brotan boiler, even that designed for our most recent locomotives, represents a perfect type of a locomotive boiler. It must not be forgotten that the ordinary boiler with fire-box has developed during the long period of eighty years, while the Brotan boiler has only been in existence a few years. It is hence quite natural that in the latter case unexpected trouble should occasionnally arise.

The most serious defect which we have found in the case of these boilers was the development of small blisters observed on two locomotives, after the one had been eighteen months in use and the other between seven and eight months.

In time, these blisters developed into cracks which made it necessary to replace the tube affected. In order to investigate the cause of these incidents, I examined the locomotives myself, and in my opinion there is no doubt that these blisters which ultimately produced cracks were due to the fact that the quick circulation of the water in the tubes of a Brotan boiler was occasionally momentarily interrupted while running. The reason was as follows : when one talks of a Brotan boiler, one thinks of a fire-box where there is but little risk if the water-level drops. As the whole fire-box is formed of tubes of small diameter, one is tempted to think that any drop in the water-level, even if the tubes become strongly heated, can not be of particular importance. I have on the contrary found that the Brotan boiler is, from this point of view, a very delicate boiler. This is not a question of any danger of explosion, but of deterioration of the tubes. The figure 1 shows that in the upper part of the tubes, the circulation of the water is reduced as follows : the

water pasing out can not mix with the boiler and pass into the latter except by passing through the lateral section obtained by imagining the tubes in question extended up to the surfaces of the water, that is up to AA′ and BB′. All the water

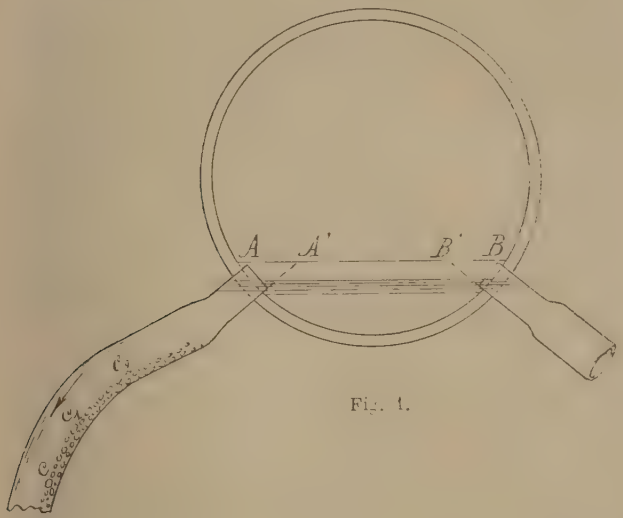

Fig. 1.

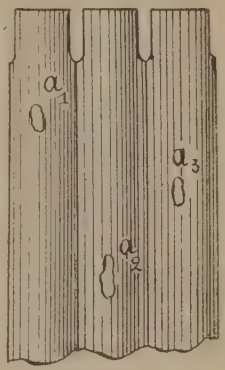

Fig. 2.

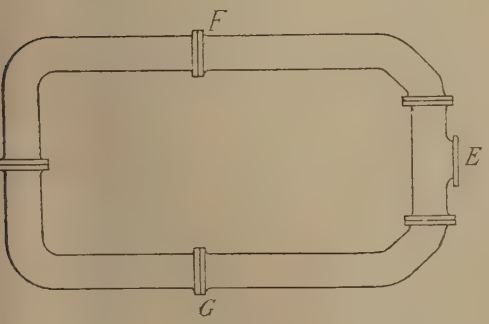

Fig. 3.

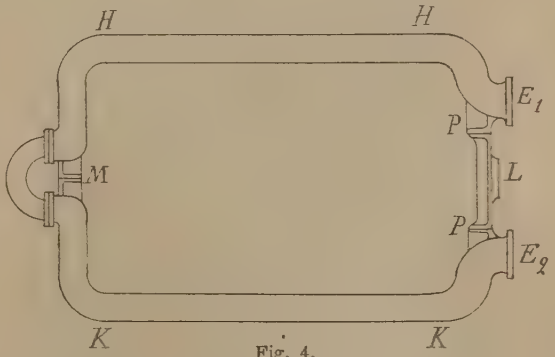

Fig. 4.

rising in those tubes is forced to pass through this section, which becomes smaller as the water-level drops, so that finally the circulation of the water may meet with so much resistance as to stop completely. There is then a circulation in each tube itself : the bubbles of steam rise from the side of the tubes exposed to the fire, while the water flows down the outer side of the latter. Then the inner side is not cooled and the surface exposed to the fire can accordingly become strongly

heated. If in addition there is a little scale, or some other unfavourable condition, if at the moment the engine is doing much work and much steam is produced, the cooling of the inner part of each Brotan tube can only take place in an imperfect manner. It is evident, in cases of this kind, that the tubes must deteriorate; and experience shows that the blisters are always produced at the middle of the semicircumference of the tubes, that is to say at the points most exposed to the action of the fire, as shown in figure 2. Consequently we have been led to advise the drivers to take care, particularly in the case of the Brotan boiler, that the water-level does not drop too much. As far as I know, no further deterioration has occurred. Another defect often observed is due to the design. This defect, which has often necessitated very expensive repair, arises from leaks at the joints of the different tubes forming the foundation ring. In this case, matters may be said to be troublesome, for in case of any leak there the whole fire-box has to be taken apart in order to cure the leaks. We have therefore thought is advisable to modify the design and I can say that a material improvement has resulted. (See figures 3 and 4; the former shows the design of the earlier foundation rings, while the latter shows the most recent design.) Figures 3 and 4 show that the number of the flanged joints, originally five, has been reduced to one. This could also be eliminated by joining the two parts of the tube by means of a bent piece of copper with spherical-face joints at both ends, which can easily be taken apart at any moment. In this way we have obtained a form of foundation ring with no flanges difficult to keep tight. I think I can say that thanks to this design we have remedied the most serious disadvantages which the Brotan boiler presents in practice.

I will not read out the other conclusions to you, I will merely add a few words in connection with one of them. It seemed to us, at first, that the Brotan boiler produced steam which was as dry as that produced by the ordinary locomotive boilers. If the steam were less dry, it would not be possible to explain the saving in steam. I must now withdraw this statement. The apparent dryness of the steam produced by our Brotan boiler must be attributed to the fact that owing to a better separation of the water, the steam contains less. This circumstance is hence not due to the boiler proper.

It should also be mentioned that seeing the much-improved water-intercepting devices now available, the wetness of the steam generated in the Brotan boiler is of minor importance. I can accordingly assert that now these disadvantages have been removed, all the conclusions concerning the Brotan boiler seem to be justified, and as far as I can sum up the present state of affairs, I can assert without hesitation that, subject to certain precautions, the Brotan boiler, if properly managed, can be very well recommended for future use. If from time to time, any defects show themselves in new designs of this type, we must remember that this is a boiler of a type which is entirely new, with which our employees are by no means as well acquainted as with the boilers of the old type. This circumstance also justifies us in expecting better work from the Brotan boiler in the future.

Allow we now to pass to the second

question, namely the use of superheated steam. I will begin by stating that only one variety of superheater is used on our lines, namely the Schmidt, but in both of its forms : in the smoke-box and in the tubes. The smoke-box superheater is only in use on nine locomotives and we are not going to make it in future. Hence I will only talk of the superheater placed in the smoke tubes. I would remark that all the advantages we have obtained with the latter we have also obtained with the smoke-box superheater, but to a rather smaller extent. That is the whole difference. The smoke-box superheater has given no trouble or difficulty of any kind. The smoke-tube superheater has given excellent results with us, both as regards the technical service and the repairs necessary. I feel convinced that superheater locomotives do not require more repair than ordinary locomotives, and are not more expansive from this point of view. For although it is incontestable that the superheater is a new addition which it must certainly cost something to repair, it has on the other hand to be noted that the superheater locomotives have sixty to eighty fewer tubes, and that is an important fact. It is also to be noted that the large tubes containing the superheater elements are much less liable to leak. So that altogether, although the addition of a superheater represents a certain increase in the cost of maintenance, there is also, on the other hand, a reduction in the cost of repair of the smoke tubes, and the two practically balance each other.

Passing now to the question of water and of fuel economy, I will record that this depends almost entirely on one given detail, nemely on the valve gear. With a good type of valve gear, one can expect with certainly that a superheated-steam locomotive will save at least 8 per cent of fuel, and often much more. In cases where superheating makes it possible to do without double heading, the saving may amount to 20 per cent or more. We use very different valve gears, and we have investigated this question carefully. We found that in designing piston valves for superheated-steam locomotives, the most important points are the width and thickness of the piston rings. With us, a thickness of 10 millimetres ($^{13}/_{32}$ inch) and a width of 20 millimetres ($^{25}/_{32}$ inch) have been found advantageous. We have two such rings at each end of the piston and we have found this the simplest and cheapest system; in future we shall use pistons of this kind only. Another peculiarity which exercises a great influence on the economy is the design of the stuffing-boxes; those recommended by Schmidt haven given us very good results. The piston rod requires much care; the metal packing then remains tight for a long time and is very durable, very practical and very economical. Provided attention is paid to these details in the case of superheated-steam locomotives, I repeat that their use gives rise to no trouble of any kind and that they are superior from every point of view to our older locomotives, not only for hauling fast trains, where the great fluidity of superheated steam is of very great importance, not only for hauling through goods trains, but also and especially for a service which has hitherto given us much trouble, I mean the suburban service. We have found that the single-expansion locomotive

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with superheater attains its regulation speed much more quickly and hence there is a considerable saving of time. We can accordingly warmly recommend the use of superheated-steam locomotives for this service as well. One class of locomotives alone has given us considerable trouble, and we have had to make many experiments before we obtained satisfactory results. Those are the locomotives which I have called in my report locomotives with divided adhesion. In this case it is of much importance that both engines should do the same work whatever the conditions. It is for this reason essential that the intermediate receiver should only receive steam which has done work in the high-pressure engine. If besides this steam, a certain amount enters which has passed through leaks in the high-pressure valve, the pressure in the receiver exceeds the calculated and determined amount. The work of the high-pressure engine becomes reduced, and that of the low-pressure engine becomes increased, and the wheels of the latter slip, which involves waste of work and useless wear of the tires. This is remedied by dividing the valve gear so as to enable the driver at any moment to adjust the high-pressure and and the low-pressure engines so as to do equal work. Provided these conditions are satisfied, I can definitely assert that superheating gives great economy in the case of the Mallet compound locomotive and that this locomotive is one of the best types, presenting great advantages from the point of view of smooth starting, of an economic steam consumption and of easy running round curves.

This is all that I have to add to my report. Allow me also to say a word about the new Stumpf valve gear. We have a locomotive fitted with this gear, and I must record that it works very well and gives rise to no remarks. There is a solitary but very serious disadvantage, and that is the excessive violence of the exhausting steam. Although the weight of steam may be exactly that required for keeping up the draft required, the vacuum produced, at the moment the exhaust starts, is so great that the fire is disturbed and a large quantity of coal is carried away. We have succeeded in reducing this disadvantage by interposing in the exhaust pipe a chamber having a capacity five times and a half that of the cylinders, in which the steam can expand. The Stumpf gear has given very good results since. We may say that this gear is very simple and hardly requires repair, as it practically has hardly any wear.

Mr. Fowler. — The following are the conclusions drawn from Mr. Vaughan's report :

Water-tube boilers. — None of them are in use.

Steam superheaters. — An appreciable saving in coal results from the use of steam superheaters. This saving is greater with passenger locomotives than with goods locomotives, but the increase of power which results in the latter case is equally advantageous.

The possible increase in cost of maintenance and an increase in engine failures can not be considered serious.

Feed water heaters.— None are in use, but in some cases the exhaust steam from the pump is led into the tender.

Mr. Steinbiss, *reporter.* (In German.) — A) *Water-tube boilers.* — Water-tube

boilers are not in use. On the other hand, two locomotives on the Prussian-Hessian State Railway, one on the Swedish State Railway, and two on the Swiss Federal Railway, have now for a short time been in use, which are equipped with water-tube fire-boxes, so called Brotan boilers. The Prussian State boilers have not satisfied expectations in the two years in which they have been in use, as the water tubes in the fire zone suffered material deformation and wear. This disadvantage is to be counteracted by adding firebrick walls. The Swiss and the Swedish trials have not yet led to any results.

Special systems of water tubes in the fire-boxes are not used.

Analyses of smoke-box gases of water-tube boilers. — No such analyses have been made.

B) *Steam superheaters and valve gear for superheated-steam.* — By far the greater number of all the superheated-steam locomotives in use (now as many as about 2,000) is to be found on the Prussian-Hessian State Railway; the results obtained there are accordingly considered in some detail below.

The systems used are :

a) The Schmidt smoke-box superheater;

b) The Schmidt smoke-tube superheater;

c) The Pielock superheater;

d) The Clench-Gölsdorf superheater;

e) The Ranafier system (superheating the steam in the intermediate receiver).

Most of the administrations use the Schmidt smoke-tube superheater, while the smoke-box superheater is now no longer made. The Pielock superheater is used on twelve locomotives of the Prussian-Hessian State Railway, on one locomotive of the Stockholm-Rimbö Railway and on six locomotives of the St. Gothard Railway. The Clench-Gölsdorf superheater is used on ten locomotives of the Baden State Railway, on sixteen locomotives of the St. Gothard Railway, and also on the Swedish State-Railway. The Ranafier superheater in used on the Oldenburg State Railway.

The superheater steam is in most cases used on twin locomotives, but of late it also is frequently used on four-cylinder compound locomotives.

Superheater in the smoke-box. — According to the statement of the inventor, Mr. Wilhelm Schmidt, engineer, the superheater tubes are made of such dimensions that the total cross-section, in square centimetres, for the steam in the superheater is about equal to 1 per cent of the piston area, in square centimetres, multiplied by the greatest mean piston speed, in metres per second.

In fixing the diameter of the smoke tubes, it is laid down as a principle that the clear cross-section available for the passage of the hot gases must not be reduced by the presence of the superheater; and it may be assumed that at the narrowest point about half the cross-section of the smoke tubes is occupied by the superheater elements. The four cross-sections of the superheater tubes occupy about 40 per cent of the clear cross-section of the smoke tubes. The proportions have given very good results.

The inventor assumes that the surface of the superheater must be equal to about 25 per cent of the total heating surface.

By putting in the smoke-tube superheater, the heating surface of the smoke tubes is reduced by a little less than 25 per cent : the total heating surface is accordingly practically not altered by the presence of the superheater, but it is materially improved by the wide smoke tubes at the top and by the superheater surface.

It also has to be taken into consideration, that the heating surface of the fire-box, which is much the most effective, remains unchanged.

The large smoke tubes and the superheater elements they contain are most easily cleaned and the soot and ashes removed by means of compressed air or steam; it is best to carry out this operation from the fire-box, but it can also be carried out from the smoke-box. Compressed air is to be preferred for this cleaning operation.

The Heusinger link motion is that used on the superheated-steam locomotives. The comparatively-long connecting rods of all classes of superheated-steam locomotives make it possible to have long eccentric rods and valve rods, and so obtain a good arrangement of this link motion, which acts well even on tank locomotives, both when running forwards and when running backwards.

As the piston valves are very tight and run with hardly any friction, it has been possible to have a long stroke, as well as a great reduction in the weight and a reduction in the size of all the details of the valve gear.

In order to obtain smooth running when the locomotive is running with regulator closed, the rotary valve of the by-pass connecting the two ends of the cylinder is opened by hand, and a connection between the two faces of the piston is then established. This device also helps to prevent hot gases from being drawn into the cylinders from the smoke-box. Air-admission valves having a clear diameter of at least 40 millimetres (1 $^{9}/_{16}$ inches) are provided for the same purpose; and these, together with the equalizing pipe, must reduce the quantity of smoke, soot and hot gases drawn in from the smoke-box.

Now that the air-admission valves are made of steed, and the smaller ones replaced by larger ones, these valves give good results. The use of the piston valves makes it necessary for the cylinders to be fitted with two safety valves, one at the top and one at the bottom; these valves are loaded to the standard pressure of the boiler. Each mud valve has also a safety valve in combination, so that each cylinder has at each end two safety valves to prevent any water-hammer effects in the cylinders when starting with them cold or if priming takes place and water is carried over. The safety valves are fitted as far as possible to the lowest points of the top and bottom of the cylinder.

The other administrations use on their superheated-steam locomotives steam pistons with three cast-iron spring rings, some with grooves and small holes, others without, made in the usual way with lapped joints, as for instance the Baden State Railway, the Swedish State Railway, the Swiss Federal Railway and the St. Gothard Railway.

The Baden State Railway, the Saxon State Railway, the Wurtemberg State Railway, the Swedish State Railway, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway use piston valves

exclusively; these contrary to the practice on the Prussian-Hessian State Railway, are fitted with spring rings of the Schmidt type. These administrations find that it is very difficult to keep piston valves with solid rings tight; in course of time they allow much steam to leak past and work uneconomically, particularly in cases of heavy work (running uphill). Their experience has accordingly led them to use spring rings for piston valves, and better results are obtained with them. The Bavarian State Railway, owing to the short time they have been in use, has not decided which arrangement is to be preferred.

In order to complete my report, I will mention that all the lines of the Prussian State Railway have recently decided to use piston valves with spring rings only.

Equalizing tubes as used on the Prussian-Hessian State Railway are also used by the Saxon State Railway and the Wurtemberg State Railway, in some cases also by the Swiss Federal Railway (without air-admission valves) and by the Rhetian Railway. These administrations consider them very useful for preventing any knocking when running with regulator closed, and for preventing injurious matter from entering the cylinders. Such equalizing tubes are not used on the Baden State Railway, the Bavarian State Railway, the Swedish State Railway and the St. Gothard Railway.

Safety valves and air-admission valves on the cylinders are used by all the administrations, except that the Swiss Federal Railway has no air-admission valves on its 2-6-0 passenger locomotives and its 2-8-0 goods locomotives, nor has the Rhetian Railway such valves in its locomotives.

Pistons rods. Metal used for the pistons, piston rings and cylinders. — The pistons on nearly all the railways, are pressed on to the taper end of the piston rod (taper 1 : 18 to 1 : 20) and secured by a nut and cotter. On the Prussian-Hessian State Railway the pistons are put on hot and secured by a nut. The low-pressure pistons of the superheated-steam compound locomotives of the Baden State Railway are screwed on and locked.

The piston bodies are made of steel castings on the Prussian-Hessian State Railway, the Saxon State Railway, the Wurtemberg State Railway, the Swedish State Railway, the Swiss Federal Railway, the St. Gothard Railway and the Rhetian Railway. The Baden State Railway uses cast-iron castings for the high-pressure and ingot-iron castings for the low-pressure piston bodies; the Bavarian State Railway uses cast iron for the latter if small, and steel castings if large. The Swedish State Railway uses a medium-hard cast steel.

Cylinders are made of hard cast iron, which is as uniform and as dense as possible and has an ultimate tensile strength of 18 to 24 kilograms per square centimetre (256 to 341 lb. per square inch); the Swedish State Railway uses cast iron to which steel turnings have been added.

Superheated-steam compound locomotives. — The Baden State Railway uses superheated-steam compound locomotives extensively; they are also used by the Bavarian State Railway, the Saxon State Railway, the Wurtemberg State Railway, the Swiss Federal Railway and the St. Gothard Railway; and the *high-pressure* steam is in all cases superheated before it

enters the cylinder. A larger number of such locomotives is on order for these railways and also for the Alsace-Lorraine Railway. In no case is the low-pressure steam superheated, or both the low-pressure and the high-pressure.

Action of superheated steam. — The results obtained depend chiefly on whether the locomotives are worked to their full power. This is so in the case of the Berlin suburban traffic; during the three months of trial an average coal economy of 15 per cent and an average water economy of 25 per cent were observed as compared with wet-steam locomotives.

Sections of line on which there are many short and steep gradients do not enable the superheated-steam locomotive to be utilized well, if the fully-loaded trains, in spite of the use of such locomotives, still require double heading and if the goods traffic on such sections is irregular, so that heavy trains which require double heading alternate with smaller trains which are not fully loaded.

The superheated steam locomotives are more powerful than similar wet-steam locomotives, as the use of the superheated steam makes it possible to have larger cylinders without increasing the boiler pressure. In consequence, double heading is materially reduced and economies made in locomotives and locomotive crews, in addition to the coal economies. It also makes it easier to run and to make a better and quicker start.

The highest temperature of the steam obtained in the heavy express service is 350° C. (662° Fahr.), and in the suburban service about 300° C. (572° Fahr).

All the administrations, in introducing superheated steam, had as their object not a reduced weight for the same power as compared with the wet-steam locomotive, but to obtain with the same weight a greater power than could be obtained from wet-steam locomotives. The attendant advantages of being able to haul heavier trains and of reducing double heading, always so onerous, and of saving coal and water when the same amount of power is utilized, more than compensate for the greater prime cost of the superheated-steam locomotives.

Moreover, of late the weight of the locomotives has everywhere been increased up to the maximum wheel-loads admissible in the different districts (standard in Germany, 8 tons [7·84 English tons]), and has thus made available a greater adhesive weight for the superheated-steam locomotive with its larger cylinders and greater thermal efficiency, so as to obtain as powerful a locomotive as possible. In doing this, the advantage remains with the superheated-steam locomotive as compared with the wet-steam locomotive, as the increase in power is relatively greater than the increase in weight.

Measurement of the superheat. Steam pressure. Ratio of total heating surface to superheating surface. — The superheat is measured in every case either in the valve chest or immediately before it, by means of the distance pyrometer made by Steinle & Hartung, of Quedlinburg.

The fall of pressure between the boiler and the valve chest is, on the average, 0·5 atmosphere (7 lb. per square inch) when the locomotive is working at full power, and varies between 0·3 and 0·8 atmosphere, according to cut-off and speed. The distance pressure-gauge for reading in the cab the pressure in the valve chests has given good results.

With increased superheat, the power of the locomotive also increases, and the coal and water economies increase according to the administration of the Prussian State Railway in the same direct ratio. Further particulars as to the relations between degree of superheat, additional power and economy obtained are not given.

The use of superheated steam has made it possible to retain the working pressure of 12 atmospheres (170·67 lb. per square inch), while the contrary was the case with wet steam, as the working pressures of such locomotives had to be raised to 14 and 16 atmospheres (199 to 227·57 lb.) when greater power was required. Almost all the superheated-steam locomotives have a working pressure of 12 atmospheres (170·67 lb.), the idea being to utilize the advantages of superheated steam with the simple arrangement of the locomotive as a twin engine, with larger boilers and larger cylinders. Recently however, higher working pressures, up to 16 atmospheres (227·57 lb.), have also been tried with superheated steam, in order to combine the advantages already obtained with those of compounding, and to be able to use on a large scale the balanced four-cylinder engine, which is favoured by some administrations. The matter is at present in the experimental stage and much interest is shown in it, more especially by the Saxon State Railway, the Bavarian State Railway, the Wurtemberg State Railway, the Swiss Federal Railway and the Alsace-Lorraine Railway.

The dimensions of the cylinders in the more recent superheated-steam locomotives are in most cases increased, as compared with wet-steam locomotives, by about 20 to 25 per cent so far as the pistons are concerned, but a considerable number of locomotives are in use which did not have the cylinders altered when they were built as superheated-steam locomotives, or else were converted into such by the addition of superheaters to existing locomotives.

Measurements of temperature. — Simultaneous measurements of the temperature of the hot gases at various points of the fire-box, the smoke tubes or flue tubes and the smoke-box, as compared with the degrees of superheat obtained at given pressures, have not been made.

Economy of fuel. Increase of power. Results of trials to determine the advantages realized in practice as compared with the theoretical advantages. — The Prussian-Hessian State Railway expresses itself as follows :

The theoretically-deduced advantages of the superheated-steam locomotives are the small condensation and the small fall of pressure between boiler and cylinder, so that the boiler output is improved.

Condensation in the superheated-steam locomotive is much reduced, as the steam enters the cylinders at high temperature and pressure. Hence it is possible to have larger cylinders, and this makes the locomotive more powerful; this is of particular advantage when starting trains.

As compared with the wet-steam boiler, the economy, the power and the heat utilization of the superheated-steam boiler rises with the power, up to a definite limit. The superheated steam locomotive is hence advantageous for heavy work, for it overcomes excessive loads more easily, should such occur.

The figures for the savings are given in a table of my report; they show that in the ordinary service and with suitable train loads the coal saving obtained by means of the superheated-steam locomotive amounts to about 8 to 10 per cent in the case of express and passenger trains and also to about 8 to 10 per cent in that of goods trains. Savings which exceed 15 per cent may be attributed to the wet-steam locomotives working under unfavourable conditions.

Apart from this, more detailed trials extending over longer periods of time have not been made or are not yet concluded, as regards the coal economy of the superheated steam locomotives as compared with the wet-steam twin and compound locomotives, taking into consideration the loads hauled, in the course of the ordinary service, over equal distances. It seems very desirable that such trials should be made on the large scale by the administrations concerned, so as to determine the economy of the increased power, per unit of coal and of steam used, realized in the course of ordinary traffic, and not merely under the special conditions obtaining when special trial runs are made.

Lubrication. — On the Prussian-Hessian State Railway the oiling of superheated-steam locomotives costs a little more, chiefly because the oil used with superheated steam is at a higher price. The four-cylinder wet-steam locomotive costs more for lubrication than the two-cylinder superheated-steam locomotive, which is of equal power.

Instructions to the staff. — On all the railways, the locomotive crews and the men in the workshops received special instruction, given by the workshop and traffic officials, in the treatment and handling of the superheated-steam locomotive; special working regulations are issued containing detailed descriptions and drawings, and models of the different superheating arrangements are also supplied. A strict supervision is moreover exercised over the proper observance of the regulations issued, both in actual working as well as when the locomotives are at the sheds and chief repair shops.

The regulations issued on the Prussian-Hessian State Railway are reproduced in appendix II of my report on question VI, littera *B*. The regulations issued by the other administrations contain very much the same instructions.

No administration gives any information as to any accidents resulting from the introduction of superheated steam.

The way indicated for the improvement of the steam locomotive is, to utilize the limited steam-producing power of the locomotive as much as possible, so as to obtain an increased economy in the working as well as increased power combined with as much saving in the weight of the locomotives as possible.

The introduction of the parallel-flow principle on the locomotive, by the use of the Stumpf valve gear, is another step forward in this direction, which promises to make the advantages of superheated steam still more apparent, while the design is as simple as possible. This system is at present being tried on the Prussian Railways.

C) *Feed-water heaters. Feeding devices.* — Apart from the comparatively-slight warming which the feed-water receives from the steam in the injectors, there is

no special provision for heating the feed-water.

Final conclusions subject VI, littera B.

a) Water-tube boilers are not in use. A few water-tube fire-boxes are in use, as a trial. There are no special systems of water-tubes in the fire-boxes.

b) Superheated steam is used more recently already on a larger scale; it is also intended to extend its use. It is to be recommended on account of the resulting economic advantages, for not only is there a saving of coal and of water, but the operation of the traffic is also facilitated by the greater power of locomotives.

The W. Schmidt smoke-tube superheater, which is generally preferred, seems at present the most suitable system for producing superheated steam. The W. Schmidt smoke-box superheater will in the future be left out of consideration. The superheaters of the Pielock and Clench-Gölsdorf designs, which are more of the nature of steam driers, have at present only received limited applications; as they are cheap and easy to build and look after, they seem useful in cases in which one is content with steam having a temperature of 270 to 290° C. (518 to 554° Fahr.).

Superheated-steam locomotives are not to be recommended for light work, particularly if the locomotives have frequent stops at short intervals, or for shunting work.

Piston valves with spring rings have given good results; piston valves without spring rings can not be recommended; flat slide valves are no more used, valve gear of the Lentz type is at present being tried.

With steam superheated to from 320 to 350° C. (608 to 664° Fahr.), the economic results prove satisfactory. The design of the new packing for the valve and piston rods can resist the deleterious influence of this high temperature just as successfully as the quality of the lubricating oil now obtainable for superheated steam.

Superheated-steam compound locomotives with four cylinders are now frequently used, and progress in this direction seems to promise good results.

The continuation of the trials of locomotives utilizing the parallel flow principle is to be recommended.

Careful and accurate trials, extending over longer periods of time, in order to compare the performance of superheated-steam and wet-steam locomotives as regards the actual increase of power and the coal and water economy really effected in regular service, should, as the results so far obtained vary considerably, be carried out by the different administrations on a large scale as soon as possible, in order to determine the value of superheated-steam more accurately. Particular attention should also be paid to the counterbalancing of the greater initial cost and the possible but as yet very uncertain increase in the cost of maintenance and repairs.

c) Devices for heating the feed-water to higher temperatures are not considered necessary, except by the Rhetian Railway. Injectors are generally used as being most suitable for feeding the boiler.

The President. (In French.) — Gentlemen, I propose that we adjourn till this afternoon. (*Approval.*)

Meeting held on 9 July 1910 (afternoon).

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Mr. GERSTNER, PRESIDENT, IN THE CHAIR.

The President. (In German.) — The discussion about littera *B*, question VI, is now opened.

Mr. Herdner, French Midi Railway. (In French.) — I think it of interest to mention that a little more than two years ago, we put in service two Brotan boilers of the original design, with two bodies, a *lower* body fitted with smoke tubes and an *upper* body serving as collector for the water tubes and connected with the lower body by means of pipes. These boilers were placed on locomotives of the *Mogul* type, compounds, with two cylinders, six coupled wheels 1·60 metres (5 ft 3 in.) in diameter and a leading pony truck. The locomotives of the same type had until then been fitted with boilers with Belpaire fire-boxes, having a grate area of 2·15 square metres (23·14 square feet). It had been specified that the two locomotives fitted with the Brotan boiler should have the same grate area, that this should be neither increased, nor reduced, so as to obtain as nearly as possible the same evaporating capacity.

While the boilers with Belpaire fire-box had a heating surface largely consisting of Serve tubes, and attaining about 82 square metres per square metre of grate, the two Brotan boilers had a heating surface which was materially smaller as the boilers were not to be heavier than the original boilers.

The two Brotan boilers were not quite the same. At the time of their construction, we were considering the damage in the tube-plates which the Serve tubes are said to cause. Evidently the Brotan boilers were, from this point of view, to be under more unfavourable conditions as the back tube-plate, instead of forming part of an inner fire-box, is riveted around its edge to the barrel of the boiler just like the front tube-plate. We said to ourselves that if, under these conditions, we used Serve tubes, their expansion would surely produce fractures.

Thus we were led to adopt a different solution for each of the two boilers. In the one case, we retained Serve tubes; but the front tube-plate was connected with the barrel by an angle-iron ring of special shape, designed by Mr. Frémont. It is a ring which has a sort of concertina fold and allows the tube-plate to move forwards and backwards, as occasion may arise.

The other boiler had smooth tubes bent slightly upwards, such as we had used for other rather more powerful locomotives. Moreover, the front and back plates were joined together by four solid longitudinal stays.

I have already stated that the heating surface of the Brotan boiler was appreciably smaller than that of the original boilers. That of the Brotan boiler with Serve tubes was only sixty-five times the grate area and that of the Brotan boiler with smooth tubes only sixty times the grate area.

These two boilers were put in service about twenty-six months ago. They have given every satisfaction since. Neither the one nor the other shows any damage in its tube-plates. As regards steam production, they seem, if anything, a little better than the original boilers. While the locomotives of the type in question, used for a quick goods service, consume for this purpose 13 kilograms of coal per kilometre (46·12 lb. per mile), the similar locomotives with Brotan boilers consume a little less than 13 kilograms, to be exact 12·85 kilograms (45·59 lb. per mile). There is thus a reduction rather than an increase. In any case, matters are not worse than they were.

Moreover, nothing went wrong, except that in one of the boilers two joints in the lower collector became loose and we naturally had a little trouble in repairing them. We however succeeded in doing this without taking the boiler to pieces. It was possible to slip a thin piece of sheet copper between the two flanges and to caulk it, and we have had no trouble of this kind since.

As regards the water tubes, we have not observed that the scale showed any general tendency to accumulate in the tubes. Nor have we found it necessary to use any special appliances for cleaning them; it suffices to push in a rod as when cleaning the other parts of the boiler.

On one occasion, it however happened that one of the water tubes accidentally became blocked; probably because some foreign body or some piece of scale had fallen into it. At the point where the tube was blocked, a swelling formed and burst, and so produced a fracture. The swelling was reduced and the crack was welded by means of an oxyhydrogen blowpipe, and there has been no trouble since.

We are very satisfied, for the reasons stated, with these boilers which have by now been in use for more than two years and which are, I think, the first of the kind to be used in France.

Mr. Koechlin, French Northern Railway. (In French.) — The French Northern Railway has exhibited at Brussels the locomotive which Mr. Dassesse mentioned this morning. This locomotive, instead of large tubes in the fire-box, has small tubes. This alteration was made because it was feared that the large Brotan tubes might explode; it was owing to this fear that our chief engineer, the late Mr. du Bousquet, decided to adopt smaller tubes, and I should like to know whether other companies, besides the Midi as just mentioned by Mr. Herdner, have had any at all serious explosions of large Brotan tubes.

The President. (In German.) — As far as I know, there has been no explosion in Austria.

Mr. Herdner. (In French.) — You have thirty-four of these locomotives?

The President. (In French.) — The Austrian State Railway has in fact thirty-four of these locomotives, but of the original type, and we have never had any tube explode.

Mr. Rihosek, Austrian State Railway. (In German) — There has been no explosion of any of the large Brotan tubes, but there have been cracks and blisters and it has been necessary to replace some of the water tubes.

Mr. Koechlin. (In French.) — Thank you; that is all that I wished to know.

Mr. Papp, Hungarian State Railway. (In German.) — We have an express locomotive with a Brotan boiler and we also have twenty-five small locomotives with boilers of this type, which have been built in order to replace automotors. Some of the Brotan tubes on the express locomotive have become a little oval; we have no information as to the small locomotives which have just been delivered, but up till now there has been no trouble.

Mr. Ernest Gerard, *vice-president.* (In French.) — I would like to know whether the meeting agrees in principle to the statement that water-tubes boilers are to be recommended on grounds of economy?

Mr. Chabal. (In French.) — It is rather premature to assert this.

The President. (In French.) — I certainly think that such a conclusion would be a little premature and that it is not yet possible to formulate a definite conclusion. My opinion is that the trials made are by no means conclusive.

Mr. Ernest Gerard. (In French.) — There is however no opinion to the contrary?

Mr. Dassesse. (In French.) — There is no opinion for, or against.

Mr. Chabal. (In French.) — We must refrain from this.

I can give my colleagues some information about the Robert boiler. On our Algerian lines, we have had a certain number of locomotives fitted with these boilers and we have found one disadvantage. In this boiler there are no smoke tubes, but only water tubes. Instead of having water tubes for the fire-box only, they are there for the barrel as well. Under these conditions the gases produced by the combustion do not flow in a determined direction, they are badly guided and even not at all and become distributed very irregularly. It thus happens that in certain parts of the boilers the gases flow properly while in others they flow too slowly and abundant deposits of soot are formed; that is at least what has happened with the locomotives which we tried in Algiers. Thus the fuel was utilized badly and moreover there was great difficulty in removing the soot; this was a laborious and very troublesome operation.

We were to have built two locomotives with Robert boiler for our metropolitan system, that is to say for our French system proper, but we decided only to build one. The trials of this locomotive have begun, but we do not yet know the results. We can however say that the first experiments made in Algiers are not very properly conducted. Attempts have been made to utilize screens in order to prevent the gases from stopping at points where they should not do so and to direct them there where they should go, but this involves a series of troublesome experiments and as yet no very favourable results have been obtained.

Mr. Koechlin. (In French.) — It is precisely owing to the trouble which the chief engineer of the Paris-Lyons-Mediterranean Railway has just mentioned that the late Mr. du Bousquet did not wish to utilize water tubes except for the

fire-box, where the temperature is sufficiently high to burn up any soot which might deposit on the tubes. It is for this reason that with our locomotive the hot gases, like with other locomotives, finish by passing through a set of tubes.

Mr. Dassesse has recommended our colleagues to go and see our locomotive at the Brussels exhibition. If any of you propose to do so, we are of course ready to give you any information you may desire.

A note on the subject of our locomotive has recently appeared in the *Revue générale des chemins de fer*. Those interested in the question, who do not receive the *Revue*, need only address themselves to me.

The President. (In German.) — Gentlemen, I think that I speak for all of you, in thanking the delegate of the French Northern Railway for his kind offer.

I think that we can now, as in the case of the other questions, draw general conclusions from the different separate conclusions submitted by the reporters.

We now start on the question of superheated-steam locomotives.

Mr. Slobodsinsky, Russian State Railway. (In French.) — Among the Russian lines, there is one from Orenburg to Tashkend, which runs through a district where is very little water. The question of superheating is hence of great importance to this line. In particular there are two points on this line where water is so scarce that it was absolutely necessary to find some means of working economically. On that line we have put in service passenger locomotives with Schmidt superheater in the smoke tubes, and with these single-expansion locomotives we have realized a saving in water of 20 per cent. In our calculations, we took as basis 1,000 axle-kilometres (621 axe-miles); this is the unit used in calculating the saving realized.

During the last two years we have had about two hundred locomotives of this type built; these have been put in service not only on this line but also on other lines, and the administrations of the different lines declare that they are fully satisfied with the work done by these locomotives and that they desire to have more of them in order to improve the train service.

Mr. Zehnder, Bavarian State Railway. (In German.) — I can quote some figures showing the economy in fuel of locomotives with superheaters. We have sixty 4-6-0 express locomotives in use, thirty-nine of them being without and twenty-one with superheater. The mean consumption of fuel per locomotive-kilometre was 13·4 kilograms (47·54 lb. per locomotive-mile) in the case of locomotives without superheater, and 11·3 kilograms (40·09 lb. per locomotive-mile) in that of locomotives with superheaters. That is an economy of about 15 per cent in favour of the locomotives with superheater; and the disadvantages are nil.

The President. (In French.) — Do not some of our colleagues feel inclined to consider the question whether, in the case of locomotives using superheated steam, it is advisable or not to adopt compounding?

Mr. Nadal, *reporter*. (In French.) — I can supply some information which will

probably interest the members of the Congress. Last May (1910) I made experiments with a four-cylinder superheated-steam compound locomotive. These experiments were made on the fast trains towards England via Dieppe.

The train weighed 270 tons and the distance from Paris to Rouen, 140 kilometres (87 miles), must be covered in 104 minutes. The records which I took enabled me to integrate both the indicated horse-power and that at the drawhook of the tender. I have not yet been able to work out all the diagrams and I only give you the results as regards indicated horse-power

The consumption of water was 8·30 kilograms of steam per indicated horse-power (18·55 lb. per indicated British horse-power). One as a rule assumes with compound locomotives a consumption of about 10 kilograms (22·35 lb.). I only inform you of the figure, 8·3 kilograms per indicated horse-power (18·55 lb. per indicated British horse-power). That is the result of trials made with a locomotive with the superheaters placed in the smoke tubes; the temperature of the superheated steam slightly exceeded 300° C. (572° Fahr), varying between 300 and 310° C. (between 572 and 590° Fahr.).

The President. (In German.) — What was the drawhook figure?

Mr. Nadal. (In French.) — I have not yet enough data to be able to say. As the trials were made quite recently and the calculations are not yet completed, I must for the moment be satisfied with giving you the consumption per indicated horse-power, that is per horse-power in the cylinders. This figure has been obtained from a very large number of diagrams, which make it possible to do the calculation very quickly. I must add that in order to make the run in question, which is practically on the flat, the mean power required for a train weighing 270 tons is 850 horse-power.

Mr. Ernest Gerard. (In French.) — Mr. Nadal will allow me to ask whether this simultaneous application of compounding and of superheated steam has given rise to any trouble?

Mr. Nadal. (In French.) — None.

Mr. Ernest Gerard. (In French). — From no point of view?

Mr. Nadal. (In French.) — Absolutely from none.

Mr. Ernest Gerard. (In French.) — Did the locomotive run as smoothly when hauling?

Mr. Nadal. (In French.) — Absolutely, and I am convinced that from this point of view the combination of compounding with superheating must offer advantages, for it makes it possible to retain flat slide valves for the low pressure.

I must add that the locomotive in question has piston valves only, but if we make any other applications of the same type, we shall have flat slide valves for the low pressure.

The President. (In French.) — You will not do so! (*Laughter.*)

Mr. Herdner. (In French.) — We have done so!

Mr. Ernest Gerard. (In French.) — Allow me to go a little further in this cross-

examination and ask Mr. Nadal a question which the President meant to ask him. Does Mr. Nadal think it would be more logical, when applying superheating to a four-cylinder locomotive, to have the four cylinders equal?

Mr. Nadal. (In French.) — I prefer compounding.

Mr. Ernest Gerard. (In French.) — I should like to know whether, in the opinion of the members present, the advantages obtained with superheating, if one had four equal cylinders, would disappear if one made the four cylinders unequal in order to have a compound, or whether there is any advantage in applying compounding and superheating simultaneously. Within the limits of his experience, Mr. Nadal has just given us a very definite answer; but if opinions are generally unsettled, it would be advisable for everybody to give his own.

Mr. Nadal. (In French.) — I do not think that this question can be decided.

Mr. Ernest Gerard. (In French.) — It is not a question of deciding it, but perhaps some members have some information they can give us about investigations made or trials undertaken, and if so it would be very interesting for us to know about them.

Mr. Keller, Swiss Federal Railway. (In German.) — The Swiss Federal Railway has built both saturated-steam and superheated-steam locomotives of exactly the same 4-6-0 type, with four cylinders, compounds. The locomotives are attached to two different depots and do exactly the same work; the superheated-steam four-cylinder compounds have shown a mean fuel economy of 6·5 and 3·9 per cent as compared with the saturated-steam locomotives of the same type. We also have three-cylinder single-expansion superheated-steam locomotives of the same 4-6-0 type; their consumption was greater than that of the four-cylinder saturated-steam compound locomotives. We have arrived at the conclusion that the four-cylinder superheated-steam compound locomotives are much superior to the saturated-steam locomotives of the same type.

Mr. Ernest Gerard. (In French.) — Meaning of course in the case of superheated-steam locomotives?

Mr. Keller. (In French.) — Yes.

Mr. Ernest Gerard. (In French.) — It is indispensable that the question should be clearly set. Is it a question of two superheated-steam locomotives, the one compound, the other with four equal cylinders?

Mr. Keller. (In German.) — Two locomotives of two identical types were compared; the saturated-steam locomotive has a working pressure of 15 kilograms per square centimetre (213·34 lb. per square inch) and has cylinders 360 and 570 millimetres (14 $^{3}/_{16}$ and 22 $^{7}/_{16}$ inches) in diameter, while the superheated-steam-locomotive has a working pressure of 13 kilograms per square centimetre (184·90 lb. per square inch) and cylinders 425 and 630 millimetres (16 $^{3}/_{4}$ and 24 $^{3}/_{4}$ inches) in diameter. The latter consumed less coal. The comparison of the superheated-steam locomotive, single expansion, with three cylinders (working

pressure 12 atmospheres [170·67 lb. per square inch], diameter of the cylinders 470 millimetres [18 1/2 inches]), showed that the saturated-steam locomotive had a greater consumption. The stroke of the pistons of all these three types of locomotives had a length of 660 millimetres (26 inches).

Mr. Noltein, *reporter*. (In French.) — I venture to remark that according to our experience the simultaneous use of compounding and of superheating is always advantageous, except in the case of two-cylinder compounds, where I do not think it is to be recommended. If for any reason it is necessary to use four-cylinder compounds, it is advisable to use superheating as well. The two-cylinder compound has the disadvantage of starting too slowly, and there is no way of remedying this. On the other hand, it was found that the combination of compounding and superheating was always advantageous. Our experiments have shown that the steam in the intermediate receiver always remains superheated.

Mr. Chabal. (In French.) — Gentlemen, I do not wish to go back to what Mr. Dassesse told us this morning, for in his report he very clearly shows how we stand. As far as the Paris-Lyons-Mediterrannean Railway is concerned, we have not a sufficiently large number of superheated-steam locomotives in use to formulate any definite conclusions; we have only thirty-one of these locomotives.

The trials we made started from the following points of view. In the first place, we wanted to ascertain whether the use of superheated steam did not give any trouble from the practical point of view, from the point of view of maintenance. On the other hand we wanted to see whether the advantages which superheating showed when applied to the locomotives of certain trains, would also show themselves in the case of other trains. We have accordingly put in service, for purposes of comparison, various high-speed superheated-steam locomotives, namely four-cylinder compounds, and also four-cylinder single-expansion locomotives. On the other hand, we are comparing goods compounds with superheated-steam compounds, and old saturated-steam non-compound with goods locomotives of the same type, but fitted with superheaters.

Finally — and this will answer the question Mr. Gerard asked a little time ago — as we have to build new high-speed locomotives, of greater power than our recent types, we have built a compound locomotive and we have compared it to a superheated-steam locomotive with four equal cylinders, in order to see whether superheating without compounding gives the advantages obtained by combining superheating and compounding.

Mr. Dassesse gave the figures this morning, but I will venture to remind you of them. I will at once say that when one takes trials made with two locomotives only, one is evidently exposed to drawing conclusions from data which are not averages, which may be affected by certain errors; thus better results may be obtained with one locomotive and its driver than with another locomotive of the same type and its driver. Subject to this reservation, the following are some of the results we have obtained with high-power locomo-

tives; for we have attained 1,700 indicated horse-power, corresponding to 1,200 horse-power at the drawhook.

Comparing the locomotive with superheating only with the locomotive with compounding only, we found a coal economy of 16·5 per cent, the figure given this morning by Mr. Dassesse, and a water economy of about 19 per cent. That is certainly a result worthy of attention.

On the other hand, we made similar trials, taking diagrams and measuring the temperatures, with high-speed locomotives with bogie and three coupled axles and wheels 2 metres (6 ft. 6 $^3/_4$ in.) in diameter, the one being a compound using superheated steam, the other merely a compound. The point was to determine whether the difference would be similar. Well, we found nearly the same difference, namely 17·5 per cent, between the compound using superheated steam, and the plain compound.

Now if these trials had been made with a considerable number of locomotives, instead of with two only, and if moreover, as Mr. Dassesse remarked, they had been made with locomotives which had been in use for some time and were in the ordinary state of maintenance, instead of being made with new locomotives, it seems that one might have concluded that superheating taken alone makes it possible to obtain the advantages which are sought for by combining superheating and compounding and that it is not necessary to have superheated-steam compound locomotives.

Unfortunately, I repeat, it is only a question of a few trials made with one locomotive and driver. Under these conditions, we are rather led to draw no conclusions or at most to limit ourselves to the statement that superheating by itself gives very good results or at least seems to give them. It remains to be seen what it will do in the case of a larger number of locomotives in the ordinary service.

We are going to continue these trials and we have ordered a certain number of locomotives with superheating only; this we had not done hitherto. Next we are going to order twenty-five or thirty locomotives with both superheating and compounding, so as to have a series with which we can make comprehensive trials. As regards locomotives with compounding only, we have no intention to order any.

There is however another point which requires elucidation. In the case of locomotives which make very long runs without stops, like our expresses which run an hour and a half or two hours without stopping, the time required before the superheater acts is evidently of no importance. But in the case of goods locomotives, this may on the contrary be of very great importance. We have, for instance, trains with stops which in many cases add up to half the time allowed for the journey; these stops are numerous and often last thirty, thirty-five or forty minutes, Under these conditions, what becomes of the advantage of superheating?

We have made some trials with goods locomotives, ten of one type and ten of another, and we have found no advantage in superheating. I can even say that as regards one series of locomotives, we found that the superheated-steam locomotives were inferior to the others; it is true that in this case we had doubts whether the valve gear did not leak.

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Thus this is a point which requires investigation. Even if one can assert that superheating seems advisable in the case of locomotives which run long distances without stops, either by itself, or combined with compounding, one cannot assert this (at least as far our knowledge goes) in the case of goods locomotives; and the conclusion that compounding alone is not useful in the case of express trains, does not necessarily apply to goods trains.

That is our present position and we are going to make a series of trials with three series of locomotives, from this point of view also. I therefore do not formulate any conclusions as I think it would be premature to do so.

The President. (In German.) — My administration has altogether 73 superheated-steam locomotives. The diameters of the wheels are 1·800, 1·550 and 1·450 mètres (5 ft. 10 $^{7}/_{8}$ in., 5 ft. 1 in. and 4 ft. 9 $^{1}/_{16}$ in). All these locomotives have three coupled axles; two types have a carrying axle. The different locomotives of the same pattern have given exactly the same result. The express locomotives, with few stops, show a better economy of fuel than the goods locomotives. Our locomotives can be readily compared because we only use very similar types, with three coupled axles : two cylinders for saturated steam, the same type, but compound, for saturated steam, the same type with three cylinders, but compound, for saturated steam and the same type with two cylinders, single-expansion, for saturated steam. We have made a whole series of trials. Unfortunately we can make no comparison of four-cylinder saturated-steam compound locomotives with locomotives with superheaters, as the latter would be too heavy for our tracks and bridges. But we can assert with certainty that the superheated-steam locomotive is superior to all these types. And here it is not a question of results obtained by comparative trials made with two locomotives. Our experience applies to two series of forty locomotives — hence the personal equation of the drivers becomes negligible — and we have found that the goods locomotives always showed a saving of 8·5 to 9 per cent in fuel and of 24 to 25 per cent in water.

Mr. Chabal. (In French.) — As compared with saturated-steam locomotives?

Mr. Ernest Gerard. (In French.) — Are those not through trains?

Mr. Herdner. (In French.) — We have figures which confirm those which the president has just given and which lead me to conclude that the application of superheated steam to goods locomotives is not to be condemned in too off-hand a manner.

I will mention the line from Béziers to Sévérac. On this line, which it is true is very undulating, we hauled our goods trains, until within the last few years, by means of compound locomotives with four cylinders and four coupled axles, a leading pony truck, a working pressure of 15 kilograms per square centimetre (213·34 lb. per square inch) and a grate area of 2·80 square metres (30·14 square feet). As these locomotives did not prove satisfactory from the point of view of the life of the boiler, we recently replaced them by single expansion superheated-steam tank

locomotives, with two cylinders 63 centimetres (24 $^{13}/_{16}$ inches) in diameter and five coupled axles, having a grate area of 2·70 square metres (29·06 square feet) (accordingly rather smaller than that of the compounds) and a working pressure of 12 kilograms per square centimetre (170·67 lb. per square inch) only. Well, these locomotives can haul, on steep gradients, 35 per cent heavier loads than the compounds. Their tractive power is accordingly very superior. However, for reasons of prudence, in order to take care of the couplings, we have at present remained satisfied with making them haul the same loads as the compounds. But while the latter consumed on the average 28 kilograms of fuel per kilometre (99.34 lb. per mile), the superheated-steam locomotives only consume 24 to 25 kilograms (85·15 to 88·70 lb. per mile), and this represents an economy of about 12 per cent.

However, it seems that this economy is not wholly due to the fact that the steam is superheated in these locomotives, while compound expansion is used in the other cases. It seems that part of it is due to the fact that the boilers of the superheated-steam locomotives work better than the boilers of the saturated-steam locomotives; in the latter case, it is more difficult to keep the tube-plate tight.

The President. (In French.) — Owing to the pressure, no doubt?

Mr. Herdner. (In French.) — Certainly. I think however, speaking in a general way, that the life of a boiler is more a question of the profile of the line than a question of the working pressure. We have used similar boilers for high-speed locomotives which run on lines with easy profiles and these boilers keep in very good condition. The results are quite different when these same boilers are on locomotives used on very undulating lines, with up and down gradients of up to 33 per mil. When on such a profile a highest point is passed, the waterlevel suddenly drops in the water gauge. The driver is accordingly induced to feed his boiler, all the more so as it is generally rather empty, and that at the exact moment when owing to the reversal of the gradient, the intensity of the fire on the grate drops from a very high maximum to a very low minimum. Such sudden cooling, repeated several times per day, is very injurious to the tube-plate.

To return to the comparison I have mentioned before, I think I must state that an increase of power of 35 per cent was recorded during the runs on the up gradient of 33 per mil, during the experimental trials described by Mr. Dassesse in his report. On the other hand the fuel consumptions which I have mentioned are monthly means and the 12 per cent saving observed in favour of the superheated-steam locomotive applies to practically equal average loads.

Mr. Paul-Dubois, Orleans Railway. (In French.) — I can also supply some information about the application of superheating. On the line from Tours to Bordeaux, we have successively hauled the goods trains with three types of locomotives, ordinary single-expansion locomotives, compound locomotives with four coupled axles and two cylinders without superheater, and compound locomotives with five coupled axles and superheater.

The consumptions during a prolonged period of ordinary service, per 100 ton-kilometres, were : simple-expansion locomotives, 2·90 to 3 kilograms (10·45 to 10·81 lb. per 100 English ton-miles); compounds without superheating, 2·70 kilograms (9·73 lb.); compounds with superheating, 2·40 kilograms (8·65 lb.). The line in question is very nearly level.

The President. (In French.) — The ratio is thus nearly the same as that of 27 to 24 kilograms (95·79 to 85·15 lb. per mile) mentioned by Mr. Herdner.

Mr. Paul-Dubois. (In French.) — It is the ratio from the point of view of the comparative consumption of single-expansion locomotives, of compounds without superheating and of compounds with superheating. We have compared the three types.

Mr. Noltein. (In German.) — In the case of the four-cylinder compounds, it is then the combination of superheating and compounding which is to be preferred?

The President. (In French.) — Clearly.

Mr. Lacoin, Orleans Railway. (In French.) — It should be noted that in the case of the Tours-Bordeaux line there is an easy profile on which the weight of the locomotive is not a large factor. That is not so on undulating lines, where the weight makes a great difference. On our lines with gradients of 25 per mil, we tried, for purposes of comparison, just like the Midi Railway, a tank locomotive with five coupled axles and two cylinders, single expansion, using superheated steam, and a compound locomotive, with four coupled axles and pony truck, with tender; the weights of these two locomotives are very different although they haul the same loads, and this difference in the weight seems to account for the difference of consumption on a very undulating line. On the contrary, in the trials of which I have the results, it is a question of locomotives running on a nearly level line, with gradients of 5 per mil only. Thus it is the superheating alone which exercises its influence, and not the weight of the locomotive.

Mr. Ernest Gerard. (In French.) — It would be interesting to hear, from any delegates present who have investigated the question, whether, when using superheating on compounds, it is better to place the superheater before the high pressure or to have it between the high and the low pressure.

Mr. Salomon. (In French.) — I can answer Mr. Gerard's question, but only part of it. At Brussels, we have exhibited a locomotive with which we intend to make experiments later on; in it the superheater is arranged so that we can in the first place heat the steam between the boiler and the high pressure, and secondly between the high pressure and the low. We have four exactly similar locomotives in use and the few experiments we have made — for this is only a beginning — have shown us that one very soon encounters a great difficulty. It is in fact necessary to pass through the superheater, instead of a given volume, four times that volume; consequently the low-pressure superheater must be given enormous dimensions, or else the high-pressure exhaust may encounter an

enormous back-pressure, so that one exceeds the pressure of 6 kilograms per square centimetre (85·34 lb. per square inch) for which the intermediate receiver is generally designed. Steam is then lost and above all there are great pressures in the low-pressure cylinders, which stop the engine.

The locomotives of the kind we have, work perfectly with small loads and when a speed of 80 kilometres (49·7 miles) per hour is not exceeded; but when it is desired to run at 110 or 120 kilometres (68·4 to 74·5 miles) per hour, the locomotive works very badly and the consumption is enormous.

We have made these experiments more especially with a view, on the one hand, to using ordinary lubricating oil while superheating less, and on the other hand, to keep the mechanism at a lower temperature and to avoid, in our high-speed services, any risk of seizing while running, and consequently stopping.

Mr. Ernest Gerard. (In French.) — Does Mr. Salomon think that the same difficulty would arise if one only had a superheater in the receiver?

Mr. Salomon. (In French.) — The practical difficulty would evidently be smaller as there would be only one single superheater to find room for on the boiler, but it would none the less remain true that the low-pressure superheater would require a clear internal cross-section four times as large as that of the Schmidt superheater or of any other similar high-pressure superheater. Now as regards our boilers, and particularly those of our express locomotives which have reached the limit of their weight, we have difficulties of all kinds in finding room for the superheater.

Mr. Antochine, *reporter.* (In French.) — I should like to know the speeds of the fast trains and of the goods trains. Can you not give us the figures?

The President. (In French.) — As for us, we call 90 kilometres (56 miles) per hour a high speed. We do not exceed this speed. As regards goods trains, the running speed depends on the gradients and varies between 15 and 35 kilometres (between 9·3 and 21·7 miles) per hour. We have also many locomotives of the goods locomotive pattern which haul stopping trains and then run at about 50 kilometres (31 miles) per hour.

Mr. Herdner. (In French.) — Mr. Gerard has just asked the following question : should the superheater be placed at the entrance to the high-pressure cylinders or between the high-pressure and the low-pressure cylinders? Now, I think I recollect that at the Liége exhibition there were two Belgian locomotives which only differed from each other in the arrangement of the superheater. In one of them, it was arranged so that it only superheated the steam entering the low-pressure cylinders. In the other, the steam could be superheated as desired, either only when entering the low-pressure cylinders, or when entering the low-pressure cylinders and also when entering the high-pressure cylinders.

I think that under these conditions Mr. Gerard should himself be able to give some interesting information about the question he asks.

Mr. Ernest Gerard. (In French.) —

Mr. Dassesse is better able to answer you than I am.

Mr. Dassesse, *reporter.* (In French.) — Those superheaters never worked. (*Laughter.*)

Mr. Ernest Gerard. (In French.) — As for me, I think it would be a great luxury to have two superheaters work together.

Mr. Dassesse. (In French.) — Neither of those superheaters ever worked. After the exhibition, both were taken out.

Mr. Ernest Gerard. (In French.) — I think it is already a great thing to have a superheater between the high and the low pressure.

Mr. Herdner. (In French.) — We are at present putting in service locomotives with both compounding and superheating, and we only superheat the steam before entering the high-pressure cylinders.

Mr. Chabal. (In French.) — In the trials we made with locomotives to which compounding and superheating were both applied, we measured the temperature of the steam during the various stages of the expansion, from the superheater to the exhaust, and although the steam was only superheated before entering the high-pressure cylinders, we still found 5 to 6° (9 to 11° Fahr.) of superheat in the steam exhausting into the chimney. It is true that we superheat to 340 and 350° C. (644 and 662° Fahr.), as recommended by Schmidt. Under these conditions we still obtain superheat in the low pressure.

Mr. Ernest Gerard. (In French.) — Then it follows that there is too much.

Mr. Chabal. (In French.) — Not too much, for at the exhaust we only find 6° (11° Fahr.), which is not far from its total disappearance; there is still a little remainder.

Mr. Herdner. (In French.) — That is still enough.

Mr. Chabal. (In French.) In the intermediate receiver, the superheat is 50° C. (90° Fahr.).

Mr. Nadal, *reporter.* (In French.) — I would make a remark similar to that of Mr. Chabal. I will refer to the trials I mentioned a little while ago. The temperature of the steam was a little above 300° (572° Fahr.); it varied between 300 and 310° (between 572 and 590° Fahr.) during 1 hour 44 minutes, and this, as I have already said, represents about 120° (216° Fahr.) of superheat. Now, at the low pressure, there still were 20 to 30 (36 to 54° Fahr.) higher than that of saturated steam at the same pressure. Thus the condition obtains that one has superheated steam not only for the high pressure, but also for the low presure, and this appears indispensable if both compounding and superheating are applied. According to the trials mentioned, it is accordingly necessary to superheat before the high pressure if one wishes to attain the result of also having superheated steam for the low pressure.

Mr. Greppi. (In French.) — I can also supply information about the trials we have made with our compound locomotive, with four cylinders, using superheated steam, and of the *Prairie* type. During these trials we observed a temperature from 300 to 350° C. (572 to 662° Fahr.) at the high pressure and from

190 to 210° C. (374 to 410° Fahr.) at the low pressure valves. Thus we always had 120 to 140° C. (216 to 252° Fahr.) of superheat at the high pressure and 40 to 60° C. (72 to 108° Fahr.) of superheat at the entrance of the low pressure. Under those conditions, it seems that by superheating at the entrance to the high pressure we also obtain steam which is still superheated at the entrance to the low pressure.

The trials which I have just mentioned were begun in November last, and were only concluded a few days ago. We have hauled numerous trains, under analogous conditions, with this locomotive and with similar locomotives of the *Prairie* type, the latter being four-cylinder compound locomotives, working pressure 16 kilograms per square centimetre (227·57 lb. per square inch), but without superheater. The difference in the consumption of fuel was in favour of the superheated-steam locomotive. In the trials made on the line from Florence to Rome, a rather-undulating line with comparatively frequent stops, the economy was 15 per cent. On the Rome to Naples line, on which there is only one stop in the one direction and only two or three on the return journey, the economy in favour of superheating was 20 per cent.

The President. (In French.) — The line is no doubt an easier one?

Mr. Greppi. (In French.) — No, it is more difficult; there are longer gradients, and there are fewer stops.

We have not obtained any appreciable increase of power and that is to be explained. Owing to the design, we could not increase the diameter of the cylinders. We accordingly obtained a greater efficiency, but without increasing the power of the engine.

Mr. Chabal said a little time ago that it would be interesting to have data based not on a few comparative trials, but on a lengthy service operated by a large number of locomotives. Now here, in order to satisfy him, I give the information I gave this morning to Mr. Dassesse, as a supplement to that which he utilized in his report. We have 100 compound two-cylinder locomotives of the *Mogul* type, which were put in service between 1905 to 1907. At present, we have on the other hand 120 single-expansion two-cylinder locomotives using superheated steam, of the same dimensions and dating from 1907 to 1910. The information refers to the service in 1908 and 1909. During the first year, we obtained a coal saving of 3 per cent only in favour of the superheated-steam locomotive. In the second year, the saving attained 10 to 15 per cent. This difference in the saving can readily be explained. The first year the superheated-steam locomotives were employed specially for hauling trains making comparatively frequent stops, while the second year we extended their field of action, and the mean frequency of stop became less. I have the complete tables here, which can be inserted in the report of our proceedings, if the section considers this information of interest. (See appendix, tables I, II and III.)

The President. (In German.) — You have accordingly used these locomotives for a faster service with fewer stops?

Mr. Greppi. (In French.) — That is to say, that besides the service they were

used for previously, they were also used for others, and consequently, in 1909, the average became more favourable. It applies to total mileages which in the case of compounds represent a little over 5 million kilometres (3,106,900 miles) and in that of the 640 locomotives nearly 3 million kilometres (1,864,200 miles).

Mr. Fowler, *reporter*. — May I ask if the provision of superheating to compounds has allowed of the pressure being reduced.

The President. — Yes, nearly everywhere.

Mr. Chabal. (In French.) — Not by adding compounding.

The President. (In French.) — I am talking of the addition of superheating only.

Mr. Chabal. (In French.) — We have in fact come down from 16 to 12 atmospheres (227·57 to 170·67 lb. per square inch). That is one of the advantages we have found in the adoption of superheating.

Mr. Greppi. (In French.) — In the last few months we have also reduced the pressure, in the case of our two-cylinder *Mogul* locomotives, from 16 to 12 atmospheres.

Mr. Fowler. — I am aware that this is the case with ordinary simple engines, but what I wished to know was whether the adoption of superheating to compound locomotives had led to a reduction in the pressure?

The President. — There has been a misunderstanding. It is a question of compounds with superheat and of compounds without superheat. In the latter case the working pressure has not been reduced. According to the information supplied, the trials with the superheated-steam compounds are not yet completed. Now the question which has been raised is whether different administrations think that superheating will by itself make up for the important advantages of the compound system; that is exactly what Mr. Chabal said some time ago.

Mr. Silva-Freire, Ministry of public works, commerce and agriculture, Brazil. (In French.) — I should like, during this discussion, to mention the conclusions we have arrived at in Brazil, from a number of experiments made with superheat. On the Brazil Central Railway, we have a section of main line about 60 kilometres (37 miles) long, with nearly continuous gradients attaining nearly 2 per cent. Five years ago, we purchased four powerful locomotives each weighing in running order, plus the tender, 206,000 pounds; two of these locomotives were four-cylinder compounds, and the two others were two-cylinder simple-expansion locomotives, fitted with the Vaughan-Horsey superheater. The working pressure of the compounds is 200 pounds per square inch and that of the superheated-steam locomotives 175 pounds per square inch. We used these locomotives for a service in which they did equal and regular work, both up and down. Finally, four years ago, we arranged for very heavy trains, as heavy as the power of the locomotives made possible. The results we obtained under these very severe conditions enabled us to establish that the coal consumption of the compounds is nearly the same as that of the superheated-

steam locomotives; but from the point of view of the maintenance and of the staff, we are much more inclined to adopt superheating. In fact, in order to obtain economic working, compounding necessitates the use of a rather skilful staff, while any driver, or a simple fireman can drive a superheated-steam locomotive which works just like an ordinary single-expansion locomotive.

The President. (In French.) — If I understand correctly, Mr. Silva-Freire is then of opinion that it takes a more skilful driver to drive a compound engine, while in the case of a superheated-steam locomotive, any driver will do. I think that I can answer him by stating that in Europe and certainly also in the United States, the locomotive crews are sufficiently educated, practically and even theoretically, in order to be able to manage a locomotive of whatever kind, and that as regards a European staff, compounding is not a difficulty.

(In English.) — Do you think, Mr. Fowler, that drivers have more difficulty in driving compound locomotives than in driving single-expansion or superheated-steam locomotives?

Mr. Fowler. — No.

The President. — As for me, I think that the education of our drivers is sufficiently complete to enable them to drive compounds without any difficulty.

Mr. Silva-Freire. (In French) — I do not mean to say that our men are not able to drive compounds — the regular running of our compounds shows they can — but simply that we can entrust a superheated-steam locomotive of the system we have adopted to a less skilful driver or even to an intelligent fireman because the superheating adopted works nearly automatically, and up till now we have had only two tubes burnt.

We propose in the future to increase our stock of superheated-steam locomotives.

The President. (In German.) — I think we can close this discussion and leave it to our reporters to draft the resulting conclusions. (*Approval.*)

Meeting held on 11 July 1910 (afternoon).

MR. GERSTNER, IN THE CHAIR.

The President. (In French.) — Gentlemen, it is necessary that I should send the conclusions of the 2nd section, concerning question VI, to the printers this afternoon. I therefore submit the following conclusions to you :

" LITTERA *A*. — The present tendencies in the construction of boilers with smoke tubes are :

" Fire-boxes continue to be made of copper in Europe and of mild steel in America;

" Fire-boxes are stiffened with stays (radial stays give satisfaction);

" Tubes of steel are adopted, unless the water is bad;

" Proper measures are applied for reducing leakage at the tubes and damage to the fire-box tube-plate.

" Serve tubes continue to be used in France and in Alsace-Lorraine.

" Hammering the copper used for the tube-plate has been found to be advantageous.

" The extended smoke-box is considered useful.

" Some administrations use, with advantage, wide and comparatively short fire-boxes, extending above the frame plates.

" The use of fire-brick arches or of other smoke-consuming devices is recommended."

— Adopted.

" Littera *B*. — 1° The water-tube boiler is only represented by the boiler with a water-tube fire-box. This type is in use neither extensively enough nor long enough, both in experiments and in practice, to make it possible to form a conclusive opinion.

" 2° The adoption of devices for drying and superheating the steam of locomotives is to be recommended; the use of superheated or at the very least dried steam gives valuable advantages : it makes it possible to obtain greater power with a slight increase in weight, and to reduce, for an equal power, the consumption of water and of fuel. These advantages appear to become more marked as the temperature of the steam and the power developed increase.

" The extra cost of construction and maintenance (it has not yet been proved that the cost of maintenance is increased) and the extra cost of lubrication are amply compensated by the saving of water and of fuel.

" By combining simple expansion with superheating sufficient power can be obtained with boilers of more moderate dimensions, using lower pressures, and this facilitates the maintenance of the boiler.

" It seems that the great fluidity of superheated steam has a favourable influence in the case of trains running at high speeds. The conjoint use of superheating and compounding tends to become extended in the case of four-cylinder types.

" Locomotives with four cylinders and with superheating only give the same results as locomotives with four cylinders and with both compounding and superheating.

" The driving and the maintenance of superheated-steam locomotives do not give rise to any difficulty.

" 3° Feed-water heaters are being tried, but in small numbers."

Mr. Paul-Dubois, *principal secretary*. (In French.) — It is said that " locomotives with four cylinders and with superheating only give the same results as locomotives with four cylinders and with both compounding and superheating." Instances of locomotives with four equal cylinders, using superheated steam, are up till now exceedingly rare These are entirely isolated cases and none of these locomotives have been in use for at all a long time. I therefore think that this conclusion is rather premature.

Moreover, our experience is in contradiction with this conclusion. For with

compounding and with superheating, we have obtained an advantage which appears superior to that attained with the superheated-steam locomotive with four equal cylinders. I think therefore that the question must remain open and that it would be rash to assume that the two types of locomotives can be placed on a footing of equality.

The President. (In French.) — I think however that I have expressed the opinion which showed itself. One could, if one liked, say : " The use of locomotives with four equal cylinders and with superheating seems to give the same results."

Mr. Paul-Dubois. (In French.) — According to us, this does not seem to do so.

The President. (In French.) — I think it would be best to strike out this sentence in the conclusions. I however regret that Mr. Gerard is not present, for I think that it was on the Belgian State Railway that the observations in this direction were made. I equally think that Mr. Chabal has also recommended the use of engines with four equal cylinders.

Mr. Dassesse. (In French.) — We have the results obtained on the Belgian State Railway and on the Paris-Lyons-Mediterranean Railway. It is those results which we have taken as basis.

Mr. Herdner. (In French.) — The sentence could be struck out.

Mr. Herscher, Paris-Lyons-Mediterranean Railway. (In French.) — It should be noted that the trials on the Paris-Lyons-Mediterranean Railway were only made with two locomotives, one with a plain compound, the other a locomotive with four equal cylinders and superheater.

The President. (In French.) — It is perhaps difficult to consider as conclusive the results of experiments made with two locomotives only. We could however retain the sentence by using in it the word " seems ".

Mr. Paul-Dubois. (In French.) — Until now, nothing of the sort has yet been proved.

Mr. Herscher. (In French.) — The Paris-Lyons-Mediterranean Railway proposes to extend the experiments already made.

The President. (In French.) — We could even limit ourselves to the statement : " The use of superheated steam locomotives with four equal cylinders is being tried. " *(Very good!)* What I want, in fact, is that the subject should not be lost sight of.

Mr. Herscher. (In French.) — The Paris-Lyons-Mediterranean Railway intends to continue, on a larger scale, the trials they have begun for comparing four-cylinder locomotives of the three types : compounding only, compounding and superheating, superheating with single expansion only.

Mr. L'Hoest, Belgian State Railway. (In French.) — We can at least record that some administrations have obtained good results.

The President. (In French.) — We can say : " ... is being tried and gives satisfaction up to the present ".

Mr. Herdner. (In French.) — Allow me to make a remark about the French wording. Instead of " *foyer tubulaire* ", it

would be better to say " *foyer à tubes d'eau* ".

The President. (In French.) — Quite right and I am obliged to you for pointing out this slip to me.

— Littera *B* of the conclusions with the amendment relating to superheated-steam locomotives with four equal cylinders is adopted.

The President. (In French.) — " LITTERA *C*. — In order to prevent any boiler damage, it is recommended to use feed-water which is as pure as possible. It is to be desired that administrations using purifiers should state the cost and the saving effected.

" Hot-water washing is recognized to be useful and can be recommended.

" Scale-separating appliances are but rarely used, and that only experimentally. Manganese bronze is sometimes used for the stays instead of copper.

" In order to avoid any boiler damage, it is recommended to select designs in which the bending effects are reduced to a minimum. "

We have adopted this text in agreement with the reporters, because we think it is very useful to recommend the administrations not to limit themselves to making purifying apparatus, but to try all means in their power to obtain feed-water which is as pure as possible, even if this involves a rather considerable capital outlay, the saving in maintenance being always a set-off against this expenditure. I think that the proposed text conveys this notion satisfactorily.

The last sentence has been taken from Mr. Antochine's report, but we all know that this is after all only a hope. (*Laughter.*)

If no objections are raised, I declare these conclusions adopted.

— The proposed conclusions are adopted.

DISCUSSION AT THE GENERAL MEETING

Meeting held on 15 July 1910 (morning).

MR. P. WEISSENBACH, PRESIDENT, IN THE CHAIR.

GENERAL SECRETARY : MR. L. WEISSENBRUCH.

FIRST ASSISTANT GENERAL SECRETARY : MR. MÜRSET.

SECOND ASSISTANT GENERAL SECRETARY : DR. A. BONZON.

Mr. Gerstner, *president of the 2nd section,* read the

Report of the 2nd section.

(See *Journal quotidien de la huitième session*, No. 10, p. 6.)

LITTERA *A*.

" The reporters presented their reports and read their conclusions.

" Mr. FOWLER (*Midland Railway*) gave the following summary of the conclusions of Mr. Vaughan's report :

" The type of boiler generally used has a round-top fire-box with radial roof stays, although about 15 per cent of the locomotives are fitted with Belpaire boilers. It has been found that the throat plates of the Belpaire boilers crack more easily.

" *Seams.* — Welded rings are being tried.

" *Domes.* — Every locomotive has a dome.

" *Stiffening.* — The back plate of the fire-box and the tube-plate of the smoke-box are stiffened, usually by rod staying, less frequently by gusset plates.

" *Fire-box staying.* — The crown stays are button-headed on the fire side. On the shell side they are riveted or fitted with a nut.

" *Stays.* — As a rule wrought iron is used, as normally specified. At some points flexible stays are put in.

" *Inside fire-boxes.* — Steel plates are universally used, usually 9·5 millimetres ($^3/_8$ inch) thick. The life varies from five to eight years. Wide fire-boxes are used on a large scale.

" *Fire-doors.* — The doors are generally on hinges.

" *Water spaces.* — The water spaces between the inner and outer fire-boxes have been increased during the past few years from 3·5 to 5 inches (88·9 to 127 millimetres).

" *Tubes.* — Mild-steel or charcoal-iron tubes are used. The ends of the tubes (with copper ferrules) are expanded and beaded.

" Mr. ZEHNDER (*Bavarian State Railway*) was desirous of obtaining more complete information about wide fire-boxes.

" Mr. STEINBISS (*reporter*) stated that the Prussian railways also used wide fire-boxes and that they had eliminated the disadvantage previously noticed, namely unequal activity of the fire on the grate, by making the ash-pan as wide as the grate. In addition the two doors of the fire-box had been profitably replaced by one.

" Messrs. NOLTEIN (*reporter*) and SLOBODSINSKY (*Russian State Railway*) stated that their administrations also used wide fire-boxes and that these worked very well.

" Mr. HERDNER (*French Midi Railway*) spoke about fire-boxes of trapezoidal shape, with which his administration was satisfied. He mentioned more especially that with this system of construction the stays remained perfectly tight.

" According to Mr. GREPPI (*Italian State Railway*), the Italian railways had actually 288 locomotives (150 of the 2-6-2 type and 138 of the 0-10-0 type) in use, with wide rectangular fire-boxes, which had given good results. At the time being some were being built with trapezoidal fire-boxes.

" Mr. ROHR (*Alsace-Lorraine State Railway*) spoke about Serve tubes, applied to a series of 165 locomotives during the last four or seven years, which worked excellently, but subject to the strict condition that they were kept perfectly clean.

" Mr. CHABAL (*Paris-Lyons-Mediterranean Railway*) stated that his company had about 1,800 locomotives in use fitted with Serve tubes, and that the latter had never given any trouble. They were cleaned carefully and regularly, by steam.

" Mr. HERDNER recalled a passage in Mr. Nadal's report, in which the Serve tubes were said to have a bad influence on the life of the tube-plates; he stated that as far as he was concerned, he had been able to make trials with six locomotives, taken out of a lot of twenty-five supplied, which had been fitted with smooth bent tubes (curvature about 35 millimetres [1 3/8 inch]) as well as with stays for connecting the tube-plates. This arrangement did not however prevent the same damage from occurring, and they had reverted to the use of Serve tubes.

" Mr. GREPPI was also of opinion that the Serve tubes were not the cause of the damage found in the tube-plates. His administration had however not considered it advisable to continue the use of these tubes in new constructions where the length of the tubes had been increased to beyond 4 metres (13 ft. 1 1/2 in.). Another reason for giving them up was their high price and the difficulty of obtaining them. As but few supplied them there was no competition.

" Mr. LAVIALLE D'ANGLARDS (*Royal Portuguese Railway Company*) stated that stays for connecting the tube-plates had been tried. These were distributed over the surface of the plates in various ways, but the experiments resulted unfavourably and stays had been given up.

" Mr. SALOMON (*French Eastern Railway*)

stated that the first impression had been that Serve tubes gave rise to trouble, but it had been recognized that this was not the case. His administration owned 500 to 600 locomotives fitted with Serve tubes.

" Mr. Chabal said that out of 1,800 locomotives fitted with Serve tubes there were at least 80 which had run about 600,000 kilometres (372,830 miles) with the same tube-plates.

" Mr. Koechlin (*French Northern Railway*) was very satisfied with the Serve tubes. For equal weights, boilers with Serve tubes had more power than boilers with smooth tubes.

" Mr. Chabal had altered a great number of locomotives simply by replacing the smooth tubes with Serve tubes. As a result the power of the locomotives had increased 10 per cent.

" Mr. Fowler (*reporter*) gave an account of trials made with Serve tubes, which were about 4·5 metres (14 ft. 9 in.) long; these trials did not prove satisfactory. Leaks were frequently formed which could only be eliminated by replacing the Serve tubes with smooth tubes."

Littera *B*.

" The reporters, Messrs. Dassesse, Fowler, Gerstner, Noltein, Fowler (speaking for Mr. Vaughan) and Steinbiss gave summaries of their reports and read out their conclusions.

" Mr. Noltein gave some further information on the trials made with the Brotan boiler since the time of drawing up his report; the actual economy effected in practice with this boiler was greater than the 3 to 5 per cent shown in the earlier trials.

" This result was due more particularly to a better circulation of the water, which produced a good effect while pressure was being got up, and reduced strains. The damage found in the case of two locomotives (cracks and bulges) had been caused by the want of water. The good circulation of the water was impeded, and consequently the cooling of the water-tubes had become illusory.

" It was of great importance to have the water-level sufficiently high.

" Repairs difficult to carry out had become necessary, resulting from a want of tightness in the joints of the flanges of the bottom reservoir.

" The design of the next boilers was consequently modified; the number of such joints was reduced to one single one, of metal to metal.

" Mr. Fowler gave the following summary of the conclusions in Mr. Vaughan's report :

" *Water-tube boilers.* — None of them are in use.

" *Steam superheaters.* — An appreciable saving in coal results from the use of steam superheaters. This saving is greater with passenger locomotives than with goods locomotives, but the increase of power which results in the latter case is equally advantageous.

" The possible increase in cost of maintenance and an increase in engine failures cannot be considered serious.

" *Feed-water heaters.* — None are in use, but in some cases the exhaust steam from the pump is led into the tender."

Mr. Steinbiss amended the conclusions

referring to piston valves for superheated-steam locomotives contained in his report as follows :

" Piston valves with spring rings have given good results; piston valves without spring rings cannot be recommended; flat slide valves are not used; valves of the Lentz design are in the experimental stage. "

I. — *Water-tubes boilers.*

" Mr. Herdner stated that two Brotan boilers of old design, with two barrels, had been working for two years under excellent conditions. One of them had Serve tubes, the other smooth tubes. The front tube-plate of the boiler with Serve tubes was fixed to the barrel by means of a corrugated piece, which facilitated expansion.

" The evaporation in these two boilers had always gone on very well. The consumption of fuel however remained practically the same as in ordinary boilers.

" During the service of these boilers, there was only one case of damage, and that not serious; one water-tube became obstructed. Below the point of obstruction, a swelling formed and then a crack. This had easily been repaired by means of the oxyhydrogen blow-pipe.

" Mr. Koechlin stated that his administration had only made the fire-boxes with small tubes, because explosions were feared with large-diameter tubes. A locomotive of this type was exhibited at Brussels and a description of it had been published in the *Revue générale des chemins de fer* (June, 1910). He asked for information as to trials of boilers with large tubes.

" Mr. Rihosek (*Austrian State Railway*) replied that no explosion had taken place with these tubes; there had only been some cracks or fissures, which had made it necessary to replace several tubes.

" Mr. Papp (*reporter*) gave similar information; he added that these disadvantages had only arisen in the case of large fire-boxes.

" Mr. Chabal gave some particulars of the trials made with Robert boilers in Algiers. The great disadvantage of this design was that the gases did not have clear passages and that deposits of soot were formed at certain spots around the tubes, and this made cleaning difficult. As this type of boiler did not satisfy expectations, their use would not be extended."

II. — *Superheated-steam locomotives.*

" Mr. Slobodsinsky stated that the superheated-steam locomotives in use in Russia gave a saving of 20 per cent in the water consumption; this advantage was much appreciated in certain countries where water was scarce.

" Mr. Zehnder informed the section that thirty-nine locomotives without superheaters and twenty-one with superheaters, had been set working concurrently in order to compare their consumptions. This amounted to 13·4 kilograms (47·54 per locomotive-mile) with wet-steam locomotives as against 11·3 kilograms (40·09 lb.) with superheated-steam locomotives; the saving with superheated-steam locomotives was accordingly 15 per cent.

" Mr. Gerstner (*president*) asked whether

compounding should or should not be adopted together with superheating.

" Mr. NADAL (*reporter*) gave some figures obtained during the trials he had just made with a four-cylinder locomotive fitted with a Schmidt superheater, hauling a 270-ton train on the Paris-Rouen section.

" He found a mean water consumption of 8·3 kilograms per indicated horse-power (18·55 lb. per indicated British horse-power) per hour, and the mean power developed was 850 horse-power. He mentioned, for purposes of comparison, that the mean for a saturated-steam locomotive was about 10 kilograms per horse-power (22·35 lb. per British horse-power) per hour.

" Mr. KELLER (*Swiss Federal Railway*) gave particulars of the respective consumption of the 4-6-0 locomotives, three types of which were in existence and were used for the same service. As compared with the saturated-steam locomotive (four-cylinder compound, working pressure 15 atmospheres [213 lb. per square inch]), the superheated-steam locomotive (four-cylinder compound, working pressure 13 atmospheres [184·9 lb. per square inch]) gave a coal economy of 3·9 to 6·5 per cent, while the superheated-steam locomotive with three equal cylinders (working pressure 12 atmospheres [170·7 lb. per square inch]) consumed still more than the saturated-steam locomotive.

" Mr. NOLTEIN (*reporter*) was of opinion that it was profitable to adopt compounding in the case of four-cylinder superheated-steam locomotives.

" Mr. CHABAL stated that the Paris-Lyons-Mediterranean Railway was making trials with several series of express and goods locomotives. These trials, which were however not yet completed, seemed to show that superheating by itself gave a saving equal to that obtained by adding compounding to superheating.

" Superheating did not give favourable results in the case of goods trains with frequent stops.

" Mr. GERSTNER (*president*) stated that in the comparative trials made with locomotives of the $^3/_5$ type with equal cylinders, the superheated-steam locomotives showed an economy of 10 per cent as compared with the four-cylinder saturated-steam compounds.

" Mr. HERDNER had obtained very good results with a goods locomotive having two equal cylinders and using superheated steam. This could haul a 35 per cent heavier load on steep up-gradients than the ordinary locomotives. Moreover, for an equal amount of work the consumption of the former was 24 to 25 kilograms (85·15 to 88·70 lb. per mile), whereas that of the latter averaged 28 kilograms (99·34 lb.).

" Mr. PAUL-DUBOIS (*Orleans Railway*) also gave some information as to trials of superheated-steam locomotives; these also were satisfactory.

" Mr. Ernest GERARD (*vice-president*) asked whether it was better to superheat the steam before the high pressure or between the high and the low pressure.

" Mr. SALOMON answered that a design making it possible to superheat before the high pressure and also at the same time

between the high and the low pressure had been used for four locomotives; one of these was at the Brussels exhibition. This design had the disadvantage of requiring an intermediate receiver of large size. Difficulties had arisen from the very beginning.

" Mr. CHABAL thought that it was enough to superheat between the high and the low pressure; for he had observed that the temperature of the exhaust steam still had a superheat of 5 to 6° C. (9 to 11° Fahr.).

" Mr. NADAL was of the same opinion, for in his experiments he had found that when the steam entered the low pressure cylinders, it still had a superheat of 20 to 30° C. (36 to 54° Fahr.); he accordingly concluded that an intermediate superheater was not necessary.

" Mr. GREPPI had made observations similar to those of Messrs. Chabal and Nadal; he also gave some particulars on the saving realized on the Italian State Railway with superheated-steam locomotives.

" Mr. FOWLER (*reporter*) inquired whether it had been possible to reduce the working pressure in the superheated-steam compounds.

" Answers were given in the negative."

LITTERA *C*.

" The reporters, Messrs. NADAL, FOWLER, ARCHBUTT, STEINBISS, PAPP and ANTOCHINE read summaries of their reports and of their conclusions.

" Mr. ARCHBUTT asked his colleagues Messrs. Antochine, Papp and Steinbiss several questions about some points in their reports, referring to water analysis, the cost of distilling water, the methods adopted for preventing the corrosion of boilers and the use of mineral oils as disincrustants. He regretted that the economic results of water purification, given by the administrations, were not given in greater detail and in a more complete form.

" The section agreed to submit the following conclusions to the general meeting. "

The President. (In French.) — The following are the

CONCLUSIONS

LITTERA *A*.

" The present tendencies in the con-
" struction of boilers with smoke tubes are:

" Fire-boxes continue to be made of
" copper in Europe and of mild steel in
" America;

" Fire-boxes are stiffened with stays
" (radial stays give satisfaction);

" Tubes of steel are adopted, unless the
" water is bad;

" Proper measures are applied for reduc-
" ing leakage at the tubes and damage to
" the fire-box tube-plate.

" Serve tubes continue to be used in
" France and in Alsace-Lorraine.

" Hammering the copper used for the
" tube-plate has been found to be ad-
" vantageous.

" The extended smoke-box is consi-
" dered useful.

" Some administrations use, with ad-
" vantage, wide and comparatively short
" fire-boxes, extending above the frame
" plates.

" The use of fire-brick arches or of " other smoke-consuming devices is re- " commended."

Littera *B*.

" 1° The water-tube boiler is only re- " presented by the boiler with a water- " tube fire-box. This type is in use " neither extensively enough nor long " enough, both in experiments and in " practice, to make it possible to form a " conclusive opinion.

" 2° The adoption of devices for drying " and superheating the steam of locomo- " tives is to be recommended; the use of " superheated or at the very least dried " steam gives valuable advantages : it " makes it possible to obtain greater " power with a slight increase in weight, " and to reduce, for an equal power, the " consumption of water and of fuel. " These advantages appear to become " more marked as the temperature of the " steam and the power developed in- " crease.

" The extra cost of construction and " maintenance (it has not yet been proved " that the cost of maintenance is in- " creased) and the extra cost of lubrica- " tion are amply compensated by the sav- " ing of water and of fuel.

" By combining simple expansion with " superheating sufficient power can be ob- " tained with boilers of more moderate " dimensions, using lower pressures, and " this facilitates the maintenance of the " boiler.

" It seems that the great fluidity of " superheated steam has a favourable in- " fluence in the case of trains running at " high speeds. The conjoint use of super- " heating and compounding tends to be- " come extended in the case of four- " cylinder types.

" The use of superheated-steam loco- " motives with four equal cylinders is " being tried and gives satisfaction up to " the present.

" The driving and the maintenance of " superheated-steam locomotives do not " give rise to any difficulty.

" 3° Feed-water heaters are being tried, " but in small numbers."

Littera *C*.

" In order to prevent any boiler damage, " it is recommended to use feed-water " which is as pure as possible. It is to be " desired that administrations using puri- " fiers should state the cost and the saving " effected.

" Hot-water washing is recognized to be " useful and can be recommended.

" Scale-separating appliances are but " rarely used, and that only experiment- " ally. Manganese bronze is sometimes " used for the stays instead of copper.

" In order to avoid any boiler damage, " it is recommended to select designs in " which the bending effects are reduced " to a minimum."

— These conclusions were adopted by the general meeting.

APPENDIX

Table I.

Service and consumption of fuel of locomotive No. 68150 with Schmidt superheater, compared with the service and consumption of the other locomotives of the same type but using saturated steam, attached to the Florence depot (period from November 1909 to February 1910).

LOCOMOTIVE NUMBER.	Mileage, in kilometres.	Mean load, hauled, in tons.	Minutes of lateness made up, per 1,000 actual kilometres run.	Gross consumption of fuel, in kilograms, total.	per actual kilometre.	per virtual 100 ton-kilometres hauled (cars).	*Remarks.*
6803	10,884	223	124	175,275	16·1	6·78	224 kilometres run with the trains used for the service of the line.
6822	4,630	187	145	66,250	14·3	7·07	Service during the month of February only.
6864	768	248	86	13,000	16·9	6·34	Service during the month of November only.
6865	16,612	178	129	244,895	14·7	7·27	
6867	19,614	216	128	294,825	15·0	6·40	
6868	2,886	218	142	41,375	14·3	6·09	Service during the months of November and February only.
6869	8,222	213	147	122,850	14·9	6·42	Service during the months of November, December and February only.
6870	17,741	216	140	277,400	15·6	6·66	
6871	12,639	222	131	224,700	17·8	7·32	
6872	21,111	229	124	343,275	16·3	6·52	
6873	19,543	223	120	326,250	16·7	6·89	
6874	9,030	216	123	137,425	15·2	6·47	Service during the months of December, January and February only.
6875	18,154	225	109	289,475	15·9	6·54	
6876	19,501	225	139	325,650	16·2	6·84	
6877	18,996	237	132	329,050	17·3	6·75	
6878	20,269	214	101	317,630	15·7	6·77	
6879	20,198	224	135	332,450	16·5	6·78	
6880	18,087	190	140	295,275	16·3	7·88	
68150	19,549	238	137	279,450	14·3	5·53	
Totals and means.	278,434	218	128	4,436,500	15·9	6·71	

Table II. **Particulars of the work and the consumption of**

Series of locomotives No.	DEPOT.	Real mileage, in kilometres, for the train service.	Real mileage, in kilometres, for the train service and the shunting operations (6 kilometres per hour).	Ratio between the virtual mileage and the real mileage for the train service.	Mean lo hauled (ca in tons
		1908			
630	Turin	618,747	622,185	1·13	197
	Venice	1,293,794	1,306,070	1·05	230
	Ancona	825,998	826,454	1·03	225
	Foligno	655,495	655,573	1·31	152
	Naples	452,659	453,685	1·26	160
	Various localities	182,732	183,008	...	...
	Total. . .	4,029,425	4,046,975	1·13	197
640	Turin	817,279	820,723	1·19	191
	Milan Central	122,331	125,085	1·09	223
	Venice	685,142	690,716	1·05	201
	Florence	11,319	11,319	1·09	206
	Total. . .	1,636,071	1,647,843	1·15	198
		1909			
630	Turin	450,851	451,961	1·18	187
	Venice	1,138,531	1,144,207	1·05	211
	Ancona	889,752	890,322	1 04	222
	Foligno	716,034	716,088	1·33	154
	Naples	1,006,753	1,007,191	1·27	164
	Foggia	470,510	471,122	1·30	159
	Bari	506,839	507,181	1·00	198
	C. Adriatic Sea	704	704	...	...
	Total. . .	5,179,974	5,188,776	1 16	185
640	Turin	1,253,354	1,256,474	1·18	200
	Milan Central	1,056,183	1,088,673	1·09	215
	Venice	479,107	482,407	1·07	198
	Total. . .	2,788,644	2,827,554	1·13	205

locomotives of the groups 630 and 640 (1908-1909). *Table II.*

Gross consumption of fuel, in kilograms.	Consumption of fuel, deducting the consumption for the shunting operations, total, in kilograms.	per actual kilometre, in kilograms.	per 100 ton-kilometres hauled (cars), in kilograms.	deducting the consumption for lighting up, shunting operations, standing still and steam heating, per 100 virtual ton-kilometres, locomotive and tender included, in kilograms.	per 100 virtual ton-kilometres hauled (cars), in kilograms.
			1908		
7,900,080	7,871,430	12·72	5·73	2·73	4·80
15,935,235	15,832,935	12·24	5·06	2·64	4·35
10,294,085	10,290,285	12·45	5·35	2·81	4·68
8,132,990	8,132,340	12·41	6·20	2·72	5·39
5,281,280	5,272,730	11·65	5·80	2·57	4·98
2,563,610	2,561,300	...	...	...	...
50,107,280	49,961,030	12·40	5·51	2·71	4·78
10,746,397	10,717,697	13·11	5·77	2·80	4·99
1,445,875	1,422,925	11·63	4·76	2·45	4·09
7,490,270	7,443,820	10·86	5·14	2·50	4·37
158,950	158,950	14·04	6·27	3·08	5·31
19,841,492	19,743,392	12·07	5·44	2·65	4·67
			1909		
5,968,400	5,959,150	13·22	5·98	2·80	5·04
14,225,500	14,178,200	12·45	5·63	2·85	4·87
11,382,995	11,378,245	12·78	5·56	2·89	4·85
8,659,765	8,659,315	12·09	5·91	2·59	5·11
11,650,060	11,646,410	11·57	5·57	2·47	4·74
6,952,280	6,947,180	14·77	7·14	3·19	6·19
6,027,015	6,024,165	11·89	5·99	2·98	5·24
8,275	8,275	...	...	...	...
64,874,290	64,800,940	12·51	5·84	2·78	5·04
14,949,685	14,923,685	11·91	5·04	2·45	4·28
12,540,980	12,270,170	11·62	4·97	2·43	4·13
5,785,500	5,758,000	12·02	5·65	2·77	4·86
33,276,105	32,951,855	11·82	5·11	2·49	4·31

Table III. **Particulars of the work and the consumption of fuel and of water of locomotive No. 68150 us**

Number of train.	DATE OF TRIAL.	Working pressure.	RUN IN QUESTION.	Actual length of run, in kilometres.	Virtual length, in kilometres.	Load hauled, in tons.	Time required (stops deducted), in seconds.	Mean running speed, in kilometres per hour.	Total work at drawbar, in kilogram-metres.	Mean tractive effort at drawbar, in kilograms.	Mean power at drawbar, in horse-power.	Work of the locomotive, virtual ton-kilometres hauled (PL_v).	Work of the locomotive, virtual ton-kilometres,
				L_r	L_v	P	T	V	A	F_u	N_u	Σ	Σ'
													Locomotive No. 681
													Trains in
21	22 Nov. 1909.	13	Florence-Chiusi.	150	201	283	8,470	63·8	223,850,000	1,490	352	56,950	89,8
21	24 Nov. 1909.	13	— — .	—	—	500	9,040	59·8	322,500,000	2,150	476	60,300	93,3
21	9 Dec. 1909.	16	— — .	—	—	(2) { 346 / 360 }	8,650	62·4	330,000,000	2,200	509	69,966	102,8
21	26 Nov. 1909.	14	Florence-Orte..	231·7	251	(1) { 316 / 337 }	13,570	61·5	481,100,000	2,075	473	80,366	124,9
21	6 Dec. 1909.	16	— — ..	—	—	(1) { 340 / 360 }	13,435	62·0	438,570,000	1,892	433	86,440	131,0
21	27 June 1910.	16	— — ..	—	—	(2) { 315 / 281 / 301 }	12,910	64·5	366,795,000	1,583	378	77,600	122,2
21	29 June 1910.	16	— — ..	—	—	(2) { 337 / 305 / 318 }	12,900	64·6	370,755,000	1,630	390	82,870	127,7
21	1 July 1910.	16	— — ..	—	—	(2) { 348 / 315 / 328 }	13,020	64·0	388,000,000	1,675	397	85,590	130,6
													Trains in
22	25 Nov. 1909.	13	Orte-Florence. .	231·7	254	(1) { 342 / 321 }	14,220	58·6	...	...	...	84,138	129,6
22	27 Nov. 1909.	14	— — ..	—	—	(1) { 356 / 334 }	13,890	60·0	511,335,000	2,210	491	87,564	132,4
22	7 Dec. 1909.	16	— — ..	—	—	(1) { 355 / 333 }	13,720	60·8	475,000,000	2,100	473	87,300	132,0
22	10 Dec. 1909.	16	— — ..	—	—	(1) { 362 / 340 }	14,060	59	...	...	...	89,250	134,9
22	28 June 1910.	16	— — ..	—	—	(1) { 340 / 319 }	13,440	62·1	346,005,000	1,492	343	83,700	128,8
22	30 June 1910.	16	— — ..	—	—	(1) { 355 / 334 }	13,810	60·3	365,805,000	1,580	353	87,450	132,2
22	2 July 1910.	16	— — ..	—	—	(1) { 358 / 338 }	13,290	62·8	381,000,000	1,645	383	88,400	133,7

(*) *N. B.*— The formula employed is as follows: $\Sigma' = PL_v + (30 + 0.7\ M)\ L_r + M + T\ (L_v)$; where P, M and T are the wei approximately to the actual lengths increased or reduced by 1 kilometre for every 5 metres of change of level; in the case of difference corresponding to the extra resistance on curves.

heated steam, and of locomotives Nos. 6874, 6801 and No. 6899, using saturated steam. *Table III.*

Consumption of water							Consumption of fuel								Coefficient of evaporation.	Remarks.
per actual kilometre, in litres.	per virtual kilometre, in litres.	per horse-power-hour at the drawbar, in litres.	per hour of run, in litres.	per square metre of heating surface, per hour, in litres.	per virtual ton-kilometre hauled, in litres.	per virtual ton-kilometre, locomotive and tender included, in litres.	total (lighting and stopping deducted), in kilograms.	per actual kilometre, in kilograms.	per virtual kilometre, in kilograms.	per horse-power hour at the drawbar, in kilograms.	per hour of run, in kilograms.	per square metre of grate area, per hour, in kilograms.	per virtual ton-kilometre hauled, in kilograms.	per virtual ton-kilometre, locomotive and tender included, in kilograms.		
ar	*av*	*air*	*at*	*as*	a_7	a_7'	C	*cr*	*cv*	*cu*	*ct*	*cg*	c_7	c_7'	$\frac{A}{C}$	
uperheated steam).																
e-Orte direction.																
104	77·2	18·8	6,640	37·9	0·274	0·174	2,080	13·9	10·4	2·5	881	252	0·0365	0·0232	7·5	(1) The change in the composition of the train normally took place at Chiusi. (2) The changes in the composition of the train normally took place at Terontola and Chiusi.
107·3	80	13·4	6,410	36·6	0·267	0·173	2,150	14·3	10·7	1·8	857	245	0·0356	0·0231	7·5	
116	87·5	14·3	7,300	41·7	0·230	0·169	2,875	19·1	14·3	2·3	1195	342	0·0420	0·028	6·1	
97·6	90	17·2	6,000	46·5	0·281	0·189	3,060	13·2	12·2	1·7	812	232	0·0380	0·024	7·5	
109·5	101	15·6	6,800	38·8	0·293	0·193	3,290	14·2	13·1	2·0	882	252	0·0380	0·025	7·7	
91·6	84·5	15·6	5,910	33·7	0·273	0·173	2,640	11·4	10·5	1·9	736	210	0·0340	0·0216	8·0	
93·0	85·7	15·4	6,000	34·3	0·26	0·17	2,650	11·4	10·5	1·9	740	211	0·0320	0·0207	8·1	
94·6	87·2	15·2	6,060	34·6	0·256	0·168	2,870	12·4	11·4	2·0	794	227	0·0336	0·022	7·6	
orence direction.																The following are the average particulars of the fuel used for the different locomotives:
104·2	95	...	6,120	35·0	0·287	0·187	3,285	14·2	12·9	...	831	237	0·0390	0·025	7·5	*Briquettes :* Calories. Calorific power . . 7,520 (1) Ash . . . . . 10.18 p. c. Volatile products . 19.89 p. c.
96·5	88	11·8	5,800	33·1	0·255	0·169	3,125	13·5	12·3	1·7	810	231	0·0360	0·024	7·1	
106·4	96·2	13·5	6,420	36·6	0·279	0·185	3,500	14·7	13·7	1·9	918	262	0·0400	0·026	7·1	
111·2	101·3	...	6,580	37·6	0·284	0·191	3,650	15·7	14·4	...	934	267	0·0410	0·027	7·0	*Coal :* Calories. Calorific power . . 7,770 (1) Ash . . . . . 7.47 p. c. Volatile products . 24.80 p. c.
87	79·5	15·7	5,400	41·4	0·241	0·156	2,450	10·6	9·7	1·9	657	187	0·0293	0·019	8·2	
87·5	79·8	14·9	5,290	30·2	0·232	0·157	2,480	10·7	9·7	1·8	646	185	0·0284	0·0187	8·1	The two classes of fuel were used in approximatily equel quantities.
90·0	82·1	14·7	5,640	32·2	0·236	0·156	2,820	12·1	11·1	1·9	764	218	0·0319	0·0211	7·4	(1) As determined by the Tompson apparatus.

of the train hauled, locomotive and tender respectively, under average conditions. — The virtual lengths correspond s steeper than 5 per mil the lengths have been reduced to $^1/_5$. To the real difference of level there is added an imaginary

Table III (cont.). **Particulars of the work and the comsumption of fuel and of water of locomotive No. 68150 u**

Number of train.	DATE OF TRIAL.	Working pressure.	RUN IN QUESTION	Actual length of run, in kilometres. L_r	Virtual length, in kilometres. L_v	Load hauled, in tons. P	Time required (stops deducted), in seconds. T	Mean running speed, in kilometres per hour. V	Total work at drawbar, in kilogram-metres. A	Mean tractive effort at drawbar, in kilograms. F_u	Mean power at drawbar, in horse-power. N_u	Work of the locomotive, virtual ton-kilometres hauled. (PL_v). Σ	Work of the locomotive,
Locomotives Nos. 6874													
Trains													
21	30 May 1910.	16	Florence-Orte. .	231·7	251	(2) { 286 253 270 }	12,530	66·5	389,070,000	1,680	413	70,041	11
BN	7 May 1907.	16	— — . .	—	—	315	12,290	67·9	386,200,000	1,670	420	79,095	12
BN	10 May 1907.	16	— — . .	—	—	350	12,400	67·3	426,400,000	1,842	460	87,840	13
BN	14 June 1907.	16	— — . .	—	—	348	12,685	65·7	424,500,000	1,832	447	87,320	13
Trains													
24	31 May 1907.	16	Orte-Florence. .	231·7	254	(1) { 352 394 }	14,590	57·2	474,210,000	2,045	433	92,073	13
NB	8 May 1907.	16	— — . .	—	—	318	13,490	61·8	423,000,000	1,830	420	80,800	12
NB	11 May 1907.	16	— — . .	—	—	350	13,840	60·2	452,080,000	1,955	436	89,000	13
NB	15 May 1907.	16	— — . .	—	—	—	13,870	60·1	450,000,000	1,940	432	89,000	13
Locomotive No. 68													
Trains													
107	6 June 1910.	16	Rome-Naples. .	249	289	270	14,310	62·6	348,480,000	1,400	325	78,200	12
107	8 June 1910.	16	— — . .	—	—	(3) { 303 291 }	14,280	62·7	347,490,000	1,395	324	86,200	13
107	10 June 1910.	16	— — . .	—	—	(3) { 302 282 }	14,450	62	352,150,000	1,414	325	85,000	13
Trains													
100	7 June 1910.	16	Naples-Rome. .	249	322	297	13,800	65	364,815,000	1,465	353	95,600	14
100	9 June 1910.	16	— — . .	—	—	298	13,920	64·4	383,130,000	1,538	367	95,950	14
100	11 June 1910.	16	— — . .	—	—	301	13,645	65·7	408,375,000	1,640	399	97,000	15
Locomotive No.													
Trains													
107	13 June 1910.	16	Rome-Naples. .	249	289	(3) { 282 266 }	14,400	62·3	346,500,000	1,390	321	79,550	12
Trains													
100	14 June 1910.	16	Naples-Rome. .	249	322	297	13,950	64·3	407,405,000	1,636	390	95,650	14

heated steam, and of locomotives Nos. 6874, 6801 and No. 6899, using saturated steam. *Table III* (cont.).

Consumption of water							Consumption of fuel								Coefficient of evaporation.	*Remarks.*
per actual kilometre, in litres.	per virtual kilometre, in litres.	per horse-power hour at the drawbar, in litres.	per hour of run, in litres.	per square metre of heating surface, per hour, in litres.	per virtual ton-kilometre hauled, in litres.	per virtual ton-kilometre, locomotive and tender included, in litres.	total (lighting and stopping deducted), in kilograms.	per actual kilometre, in kilograms.	per virtual kilometre, in kilograms.	per horse-power-hour at the drawbar, in kilograms.	per hour of run, in kilograms.	per square metre of grate area, per hour, in kilograms.	per virtual ton kilometre hauled, in kilograms.	per virtual ton-kilometre, locomotive and tender included, in kilograms.		
ar	*av*	*aiv*	*at*	*as*	*a₃*	*a₃'*	C	*cr*	*cv*	*ci*	*ct*	*cg*	*c₃*	*c₃'*	$\frac{A}{C}$	
(using saturated steam).																
ce-Orte direction.																
99·5	92·1	16·1	6,650	37·8	0·330	0·203	3,020	13·0	12·0	2·1	867	248	0·0430	0·026	7·3	(1) The change in the composition of the train normally took place at Chiusi.
106·8	98·6	17·2	7,250	39·9	0·313	0·200	3,400	14·7	13·5	2·4	906	285	0·0430	0·0275	7·3	(2) The changes in the composition of the train normally took place at Terontola and Chiusi.
123·4	113·8	18·0	8,300	37·7	0·326	0·216	3,900	16·8	15·5	2·5	842	242	0·0414	0·0295	7·3	
120·8	111·5	17·8	7,950	36·1	0·321	0·212	4,200	18·1	16·7	2·7	1,190	340	0·0482	0·032	6·7	(3) The changes in the composition of the train took place at Cassino.
Florence direction.																
129·1	117·9	17·1	7,400	33·5	0·325	0·220	3,970	17·1	15·6	2·3	980	280	0·0430	0·029	7·5	*N. B.* — For the average properties of the fuel used for locomotives Nos. 6874 and 6801, 6850 and 6899, see the information given in the first part of table III.
116·1	106·0	17·1	7,180	32·6	0·333	0·214	3,500	15·1	13·8	2·2	935	386	0·0433	0·0276	7·7	
117·4	107·1	16·2	7,070	32·1	0·306	0·203	3,600	15·5	14·2	2·1	937	387	0·0404	0·027	7·6	
119·5	109·1	16·7	7,210	32·7	0·312	0·207	3,650	15·7	14·4	2·2	948	393	0·0410	0·0273	7·6	
superheated steam).																
Naples direction.																
67·0	58·0	12·9	4,200	24·0	0·214	0·130	2,160	8·7	7·5	1·7	543	155	0·0276	0·0168	7·7	
75·4	65·0	14·6	4,730	27·0	0·216	0·138	2,500	10·4	8·6	1·9	630	180	0·0290	0·0183	7·5	
75·0	65·5	14·5	4,700	26·8	0·222	0·140	2,350	9·4	8·1	1·8	585	167	0·0276	0·0174	8·0	
-Rome direction.																
85·6	66·3	15·7	5,560	31·7	0·223	0 143	2,700	10·8	8·4	2·0	704	201	0·0282	0·0181	7·9	
89·0	68·5	15·5	5,720	32·6	0·230	0·148	2,750	11·0	8·5	1·9	712	203	0·0287	0·0184	8·0	
85·3	66·0	14·0	5,600	32·0	0·219	0·141	2,590	10·4	8·0	1·7	684	195	0·0267	0·0172	8·2	
saturated steam).																
Naples direction.																
93·8	81·0	18·2	5,850	26·6	0·294	0·182	2,950	11·8	10·4	2·2	738	211	0·037	0·023	7·9	
-Rome direction.																
102	79·0	17·3	6,560	29·8	0·268	0·172	3,250	13·0	10·1	2·1	838	240	0·034	0·022	7·8	

SECTION II : LOCOMOTIVES AND ROLLING STOCK

[621 .431.2]

QUESTION VII

STEAM LOCOMOTIVES FOR VERY HIGH SPEEDS

Steam locomotives for obtaining regulation speeds exceeding 60 miles per hour.

Reporters :

America. — Mr. William Garstang, superintendent of motive power, Cleveland, Cincinnati, Chicago & St. Louis Railway.

Other Countries. — Mr. Courtin, member of the Board of works, member of the general administration of the Baden State Railway.

QUESTION VII

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N. B. — Vide also the separate issues (in red cover) Nos. 28 and 60.

[621 .131.2]

REPORT N° 1

(America)

By Wm. GARSTANG,

SUPERINTENDENT OF MOTIVE POWER, CLEVELAND, CINCINNATI, CHICAGO & ST. LOUIS RAILWAY.

In accepting the invitation to act as Reporter for America on question VII (III of Section 2), covering " Steam Locomotives for Very High Speeds ", the direct form of the question being, " Steam Locomotives for Obtaining Regulation Speeds Exceeding 60 Miles per Hour ", the author advised the General Secretary that if the question was not modified to cover regulation speeds exceeding 50 miles per hour, that the replies for America would be so extremely limited that the report would be of no value. The General Secretary was kind enough to recognize our position and through his courtesy the question was modified to include regulation speeds of 50 miles per hour or more with the result that this report for America is amplified approximately 700 per cent over what would have been possible had the original form been adhered to.

Recognizing the distinction and honor conveyed in being appointed a Reporter for the American Continent on so important a subject to be presented before this International Association, the Author hoped to be able to give the subject an exhaustive study that would be a valuable addition to the archives, but as is usual in connection with the daily operation of American Railway Systems, countless emergency cases have arisen that have detracted our attention from the subject to such an extent that the report is in a much more abbreviated form than the writer had contemplated, and is based entirely upon the reports received in answer to questions

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propounded to the various Railway Administrations of America who are Members of this Association, and does not deal with the technical points involved to that extent that would seem desirable.

For the information of the Members, a few words regarding the service offered by American Railways, that would come within the scope of the question will be apropos, as there is a marked distinction between such service required to suit the demands of the American public when compared with European practice, especially as regards weight and general character of the vehicles used. Additionally, the dead weight per passenger carried in America is generally in excess to a marked extent, when compared with European practice, and the power required from the locomotive varies directly in relation to the ratio of dead weight when compared on a basis of a fixed number of passengers transported, the speeds and gradients being assumed uniform in the comparison.

At the solicitation of my Colleague, Mr. Alexander Courtin, of the Grand-Ducal Board of Directors of the Badish Government Railroad, who is reporter on the same subject for all Countries except the American Continent, a series of questions were formulated covering the subject jointly from our respective standpoints in order that replies from abroad and from American representatives would be framed from queries that were uniform in their phraseology and scope and therefore directly comparable, with the exception that for the American Section, distances, lineal measurements, weights surface, solid and liquid measures are reported in miles, feet and inches, tons, square feet, cubic feet and gallons respectively, instead of using the Metric System current European practice; therefore a study of the tabulated replies embodied in the latter portion of this report will be more comprehensive if the following is definitely understood.

American Railways, that is, those which operate such service as would fall within the scope of the question, are confined solely to the United States.

High Speed Service within the limits of the question, in America, does not include any vehicles in the complement of such trains that have less than four axles, that is, two axles in a pivoted Bogie Truck, with two trucks under each vehicle in all cases, and on the extremely high class luxurious trains, all of the vehicles have three axles in each Bogie Truck.

Vehicles used in American practice in all cases are fitted with end entrances over platforms, that in the great majority of instances have completely enclosed or what is known as " Wide Vestibules ", and have relegated the partially enclosed platforms, otherwise known as " Narrow Vestibules " to the less important trains.

American practice, at the hour of writing, use vehicles whose inside length between end walls is approximately 70 feet with but few exceptions which may vary from 2 to 5 feet over or under the length given according to the character of the vehicle, and it should be understood that the shorter vehicles are generally of a combination character, one end of which is used for the transportation of " Baggage ", or " Luggage " as it is commonly called in European practice.

These vehicles will vary in weight from 50 to 65 tons " Empty Weight ", and for ordinary purposes may be averaged at 57 tons when light and 59.5 tons when loaded.

High speed trains within the scope of the question, are ordinarily composed of from 6 to 8 vehicles, and taking the average as 7 and with a loaded weight of 59·5 tons, the average weight of the trains becomes 416·5 tons. The average length over faces of couplers is 78 feet, thereby making the length of the average 7 car train 546 feet from the face of the coupler at the rear of the tender of the locomotive.

American practice in the mechanical details surrounding the coupling attachments and platform vestibule fittings, require a compression of the coupler springs also the springs governing the operation of the vestibule diaphragms to such an extent as to hold the cars rigidly together and provide a walk-way that is continuous between all cars, at all times, and on account of these features, the semi-rigidity of the vehicles when coupled, is such that it becomes markedly apparent in the design and proportion of the American Locomotive whose assigned duty is to transport these trains on the high speed schedules that would fall within the zone of the question propounded.

American Railways, from a geographical standpoint are operated through territory that provides all the natural obstacles that the world affords and the characteristics of the country through which certain lines have been laid have taxed the skill of the Locating and Constructing Engineers to the limit, but the fact remains that elevations from sea level to 6,000 feet above have been surmounted. Districts of a mountainous character entail a succession of curves of acute radii that add to train resistance in excess of the grades on which they may be located, and the duty of the locomotive at such points, is not measurable in the report as there are no comparative questions that make this possible.

Progress in American Locomotive Construction, at the present writing requires boiler pressures varying from 180 to 225 lb. gauge pressure or 195 to 240 lb. absolute, the boilers being of the fire tube type with fire boxes varying from what is known as the Narrow and Deep type to the Wide and Shallow type and furnished with and without combustion chambers and are arranged to use anthracite or bituminous coal or crude petroleum according to the natural fuel of the District through which they are operated. A small percentage of American Locomotives in use to-day are equipped with Superheaters, some of these being of the waste heat form and others having superheater tubes contained within the fire tubes. American locomotives almost without exception, have outside cylinders whose axis is parallel with the top of the rail and approximately 1 $^1/_2$ inches above the center of the main axle. The cylinders have both flat slide and piston valves operated by both variable and constant lead valve gears, the variable lead gear of the Stephenson type being largely used, although the tendency of late has been towards a modified form of Walschaerts constant lead gear having all the characteristics of this gear as used in

European Continental practice with slight variations to suit American Locomotive Construction.

American locomotives of to-day embrace all practical forms known from the ponderous articulated machines for heavy mountain service to the single driver, special light machines largely used for inspection service and the range of compounding has embraced two, three and four cylinder types operating in unison on the same axle, or, connected to crank axles, the compound forms in four cylinder engines embracing both the tandem and vertical plane types. In the opinion of the writer, there is a marked tendency toward discontinuing the compounding of locomotives in Districts where fuel is cheap and the added maintenance cost more than offsets the gain in compounding.

The report, deduced from replies to questions submitted to various American Railway Members, follows in tabled form, which in a measure will show the characteristics of locomotives and equipment, including the schedules, distances traversed, with gradients, curves and trains handled under these schedules, on the respective Divisions reported, and the attention of the Congress is invited to a study of these prior to entering into any discourse on representative machines for High Speed Service.

One of the most complete reports received on the subject was that furnished by Mr. J. W. Kendrick, second vice-president of the Atchison Topeka & Santa Fe Railway and while they do not show any trains scheduled at 50 miles per hour or more, they do show trains making as high as 57 miles per hour for short distances.

We did not feel from the scope of the question assigned us to report on, that we were privileged to include locomotives that were not hauling regular scheduled trains maintaining a speed of 50 miles per hour or more, but on account of the completeness of their report, we reproduce it in appendix.

Tabulation of replies to detailed list of questions.

Tabulation of replies to detailed list of questions.

Distances reported are in United States Standard . . . Miles of 5,280 feet.
Lineal measurements are in — — — . . . Feet and inches.
Weights are in United States Standard . . . . . Tons of 2,000 lbs.

Surface measure in United States Standard . . Square feet.
Solid — — — — — . . Cubic feet.
Liquid — — — — — . . Gallons (231 cubic inches).

QUESTIONS.	New York Central & Hudson River Railroad.	New York Central & Hudson River Railroad.	Pennsylvania lines N. W. System.	Lake Shore & Michigan Southern.	Vandalia.	Baltimore & Ohio.	Chicago Burlington & Quincy.	Chicago Burlington & Quincy.
QUESTION I.								
Type of locomotives used for high speed. .	4-4-2	4-6-2	4-4-2	4-6-2	4-4-2	4-4-2	4-4-2	4-1-2
A. Number of different kinds?								
a) With detachable tenders	1	1	2	1	1	1	1	1
b) Without detachable tenders	...	...	...	...	...	...	...	...
B. Number of these locomotives used :								
aa) Classified as to kind	213	60	27	45	17	20	5	5
ab) — — —	...	...	...	...	...	...	...	...
QUESTION II.								
Principal features of permanent way governing operation and scheduled speeds.								
I. On regularly operated divisions where speeds of 50 miles or more per hour are maintained, give :								
A. Distance in miles	148·8	148·8	148·0	182	67·89	130·5	206	206
a) Average rise in grade, per cent in 100 feet . .	0·115	0·115	0·195	0·04	0·285	0·23	(1)	(1)
b) Greatest — — — — — . .	0·229	0·229	0·670	0·065	0·790	0·340	0·870	0·870
c) Total rise in feet, for maximum grade . . .	23 0	23·0	53·0	102·96	125·14	127·50	168·90	168·90
d) Length in miles of maximum grade	1·9	1·9	1·5	6·5	3·0	7·1	3·68	3·68
e) Average fall in grade, per cent in 100 feet . .	0·161	0·161	0·238	0·04	0·323	0·26	(1)	(1)
f) Greatest — — — — . .	0·19	0·19	1·00	0·0425	0·636	0·50	0·76	0·76

A. (*a* to *g*) :								
a) Average speed required to maintain schedules on divisions 50 miles or more in length . .	55	55	55·45	56·70	52·20	62	51·67	51·67
b) Greatest speed required to maintain schedules on divisions 50 miles or more in length . .	75	75	83	80	70	70	90	90
QUESTION III.								
Consist of trains used in regular traffic								
I. Size of trains (No. of cars), operated over divisions, as per question II	6	9	5	6	6	6	7	7
A. Number of axles, exclusive of locomotive . . .	36	54	30	36	36	34	38	38
B. Weight in tons, exclusive of locomotive. . . .	365	524	336	380	300	324	390	390
II. Regular car equipment used on these trains. . . .	...	...	...	...	...	...	...	...
A. Number of cars, with two axles	...	...	...	...	...	...	...	...
A. Number of cars, with three axles	...	...	...	...	...	...	...	...
A. Number of cars, with four axles	...	...	...	...	...	1	2	2
A. Number of cars, with six axles.	6	9	5	6	6	5	5	5
B. Number of cars, with no platforms	...	...	...	...	...	...	...	...
B. Number of cars, with open platforms . . .	...	...	...	...	...	...	...	...
B. Number of cars, with Narrow vestibules . .	...	...	...	...	...	...	...	...
B. Number of cars, with Wide vestibules . . .	6	9	5	6	6	6	...	...
C. Weight in tons, of individual cars in service . .	60·8	58·2	67·2	63·3	55	54	57	57
QUESTION IV.								
Length of time since entering the service and distances traversed by locomotives referred to in answer to question I.								
I. Date of entering regular service.	1901	1908	1901	1907	1903	1902	1903	1902
II. Greatest distance in miles made :								
A. Without stops	148·8	148·8	141	182	67·39	59·5	82·8	82·8
B. Without change of locomotives	148·8	148·8	148	182	169·1	130·5	206	206

(1) Indicates no information furnished.

Tabulation of replies to detailed list of questions. (Continued.)

QUESTIONS.	New York Central & Hudson River Railroad.	New York Central & Hudson River Railroad.	Pennsylvania lines N. W. System.	Lake Shore & Michigan Southern.	Vandalia.	Baltimore & Ohio.	Chicago Burlington & Quincy.	Chicago Burlington & Quincy.
QUESTION IV. (Continued.)								
III. Average yearly mileage made by these locomotives taking into consideration	90,000	90,000	74,000	60,000	105,600	60,440	79,063	87,991
A. The number of locomotives required to fill the runs and protect the service	...	...	...	...	...	...	...	...
B. The number of locomotives belonging to this service which are undergoing repairs. . . .	...	...	...	...	...	...	...	...
QUESTION V.								
Principal features of locomotives and tenders.								
I. Locomotives.								
A. Boiler.								
a) Heating surface, fire-box, inside, in sq. feet.	194·0	242 0	166·0	231·3	177·1	187·7	155·5	155·55
b) — — fire-tubes, outside, — — .	3,141·0	4,000 0	2,474	39,60·6	29,23 2	2,457·9	2,834·5	2,834·5
c) — — superheater, in square feet .	None.	None.	None.	None.	None.	None.	None.	None.
d) — — total, in square feet. . . .	3,335·0	4,242·0	2,640·0	4,141·9	3,100·3	2,675·6	2,990·0	2,990·0
e) Working steam pressure, by gauge, in lb. .	185	200	205	200	200	205	210	210
f) Height of center line, above top of rail, in inches	111	117	111	117	111	109	110	108 6
g) Length of fire-tubes, between sheets, in inches.	191	239	180	239	191	180	198	198
h) Fire-tubes, outside diameter, in inches . . .	2	2	2	2	2	2	2	2
— inside diameter, in inches . . .	1·76	1 76	1·75	1·76	1·75	1·76	1·78	1·78
i) Superheater tubes, outside diameter, in inches.	None.	None.	None.	None.	None.	None.	None.	None.
— — inside diameter, in inches.	...	...	...	...	...	...	...	...
k) Length of grate, in the clear, in inches . .	96	108·6	111	108·6	96	111	96	96
l) Width of grate, in the clear, in inches . . .	75·2	75·2	72	75·2	75 2	72	66	66
m) Grate area, in square feet . . .								

b) Position of { inside	...	...	...	...	...	...	...	...
b) Position of { outside	Yes	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
c) Diameter of, in inches	21·5	22	21·5	22	21	22	20	15
d) Stroke of, in inches	26	28	26	28	26	26	26	26
e) Volume of (area times stroke), in cubic inches.	9,439 32	10,643·7	85,81·5	1,0644	9,005·3	9,883	8,168·2	4,594·5
f) Number of, low pressure	None.	None.	None.	None.	None.	None.	None.	2
g) Position of, inside	...	...	...	...	...	...	...	...
— outside	...	...	...	...	...	...	...	Yes.
h) Diameter of, in inches	...	...	...	...	...	...	...	25
i) Stroke of, in inches	...	...	...	...	...	...	...	26
k) Volume of (area times stroke), in cubic inches	...	...	...	...	...	...	...	12763·0
l) Ratio of area of low pressure cylinder to area of high pressure cylinder	...	...	...	...	...	...	...	2·77 to 1 00
C. Factors governing general design :								
a) Ratio, of total heating surface to grate area	66·3 to 1·00	75·2 to 1·00	47·56 to 1 00	73·0 to 1·00	61·8 to 1·00	48·2 to 1·00	67·8 to 1·00	67·8 to 1·00
b) Ratio, of theoretical tractive power to the adhesive weight	0·992 to 1·00	0·74 to 1·00	1·32 to 1·00	1·00 to 1·15	1·00 to 1·02	1·00 to 1·00	(1)	(1)
c) Coefficient used in determining adhesive weight	0·235	0·235	0·25	0·20	0·22	0·25	(1)	(1)
d) Ratio, of heating surface in square feet to cylinder volume in cubic feet	305 to 1·00	344 to 1·00	559 to 1·00	340 to 1·00	595 to 1·00	463 to 1·00	632 to 1·00	1124 to 1·00
D. Wheels :								
a) Number of driving wheels	4	6	4		4	4	4	4
b) Driving wheels, outside diameter, in inches	79	79	80	79	79	80	78	78
c) Number of driving wheels with flanged tires.	4	6	4	6	4	4	4	4
— — — without — —	...	...	...	...	...	...	...	...
d) Are all driving wheels connected by coupling rods	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
e) Number of leading wheels	4	4	4	4	4	4	4	4
f) Leading wheels, outside diameter, in inches	36	36	36	36	36	36	37·25	37·25
g) Trailing wheels, number of	2	2	2	2	2	2	2	2
h) — — outside diameter, in inches	50	50·25	50	50	49	50	48	48
E. Axles :								
a) Total number of	5	6	5	6	5	5	5	5
b) Number of in pivoted truck	2	2	2	2	2	2	2	2
c. Number of in rigid frames	2	3	2	3	3	3	3	3
d. Number of driving axles	2	3	2	3	2	2	2	2

(1) Indicates no information furnished.

Tabulation of replies to detailed list of questions. (Continued.)

QUESTIONS.	New York Central & Hudson River Railroad.	New York Central & Hudson River Railroad.	Pennsylvania lines N. W. System.	Lake Shore & Michigan Southern.	Vandalia.	Baltimore & Ohio.	Chicago Burlington & Quincy.	Chicago Burlington & Quincy.
QUESTION V. (Continued.)								
F. Weights:								
a) Locomotive only when empty, in tons	(1)	(1)	81·55	(1)	84·2	78	84·9	83·2
b) Locomotive only, in working order, in tons.	95	133	91·57	131	94·5	90	93·5	91·8
c) Locomotive only, on driving wheels, in tons	52·5	85·75	59 17	86	54·2	54·7	45·6	47·9
d) Total tractive force, in lbs.	24,500	29,900	22,411	29,900	23,222	27,410	23,800	21,400
e) Ratio, of total tractive force, in lbs., to total weight on driving wheels, in lbs. when locomotive is in working order.	1·00 to 4·25	1·00 to 5·73	1·00 to 5·28	1·00 to 5·53	1·00 to 4·67	1·00 to 4·00	1·00 to 3·83	1·00 to 4·48
II. Tenders:								
A. Number of axles	4	4	4	4	4	4	4	4
B. Capacities.	...	...	...	...	...	...	...	...
a) For water, in gallons.	6,000	8,000	7,000	8,000	7,500	7,000	6,000	6,000
b) For fuel, in tons	10	14	14·6	14	12	16	12	12
C. Weights:								
a) When empty, in tons.	30·0	30·8	28·7	33·7	29·1	29·5	23·2	23·2
b) When in working order, in tons	61·0	78·0	71·9	81·0	76·5	74 7	60·2	60·2
III. Diagram showing the locomotive and tender, with principal measurements, etc., is shown by figure No.	1	2	4 and 5	2	(1)	14	15	16
QUESTION VI.								
Component parts of the locomotive.								
I. Superheaters	None	None	None	None				

C. What satisfaction has been obtained from use of superheaters :								
a) From standpoint of maintenance o. desired superheat	...	...	...	...	...	...	...	...
b) From standpoint of maintenance of parts	...	...	...	...	...	...	...	...
II. Steam distribution :								
A. Valves used, for distribution of steam to cylinders	...	...	Figs. 7 and 8.	...	...	...	...	...
a) Flat slide valves	...	...	Yes.	...	...	Yes.	...	...
aa) Balanced	...	...	Yes.	...	...	Yes.	...	...
ab) Unbalanced.	...	...	...	...	...	...	...	...
b) Piston slide valves.	Yes.	Fig.3 Yes.	Fig. 10 Yes.	Fig. 13 Yes.	Yes.	No.	Fig. 17 Yes.	Fig. 18 Yes.
ba) With spring supported sectional ring packing	...	...	...	...	...	...	...	...
bb) With solid, or what is known as spring ring packing	Yes.	Yes.	Yes.	Yes.	Yes.	...	Yes.	Yes.
c) Principals employed to prevent loss of temperature, in steam supplied to cylinders	...	...	...	...	...	...	...	...
ca) Insulating covering, valve chamber walls.	Yes.	Yes.	No.	Yes.	Yes.	No.	Yes.	Yes.
cb) Insulating covering, cylinder walls	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
cc) Steam jacketing, on valve chamber walls	No.	No.	No.	No.	No.	No.	No.	No.
cd) Steam jacketing, for cylinder walls	No.	No.	No.	No.	No.	No.	No.	No.
ce) Describe any other method, if used	None.	None.	None.	None.	None.	None.	None.	None.
d) Description of relief valves, if used	Auto' antivacuum type.	Auto' antivacuum type.	Auto' antivacuum type.	Auto' antivacuum type.	Auto' antivacuum type.	Auto' antivacuum type.	Auto' antivacuum type.	Au o' antivacuum type.
e) Description of any appliances used as a substitute for relief valves	None.	None.	None.	None.	None.	None.	None.	None.
B. Type of valve gearing, for high pressure cylinders	Stephenson.	Walschaerts.	Stephenson.	Walschaerts.	Stephenson.	Stephenson.	Stephenson.	Stephenson.
C. — — — for low — —	...	...	...	...	...	...	...	Stephenson.
Diagrams of valve gearing is shown by figure number.	(1)	11 and 12	6 and 9	11 and 12	(1)	(1)	(1)	(1)
D. Valve gearing, data on serviceability from actual service records	None.	None.	None.	None.	None.	None.	None.	None.
Data on cost of maintenance of parts, from actual service records	None.	None.	None.	None.	None.	None.	None.	None.
III. Counterbalancing :								
A. Weight of reciprocating parts, percentage of use in connection with revolving weights for counterbalancing driving wheels.	66	66	66·6	49 1	66·6	63	66	66

(1) Indicates no information furnished.

Tabulation of replies to detailed list of questions. (Continued.)

QUESTIONS.	New York Central & Hudson River Railroad.	New York Central & Hudson River Railroad.	Pennsylvania lines N. W. System.	Lake Shore & Michigan Southern.	Vandalia.	Baltimore & Ohio.	Chicago Burlington & Quincy.	Chicago Burlington & Quincy.
QUESTION VI. (Continued.)								
B. Is the weight referred to in *A* distributed in counterbalance of :								
a) All coupled driving wheels	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
b) Confined to main wheel only	...	...	...	...	...	...	...	...
c) Otherwise disposed of.	...	...	...	...	...	...	...	...
IV. Flexibility :								
A. Rigid wheel base, locomotive only, in feet . . .	7·0	14·0	7·416	14·0	7 00	7 416	7·25	7·25
B. Lateral movement provided, each side, between wheel hubs and journal boxes :								
Leading wheels, in inches	0·09375	0·09375	0·125	0·09375	0·0625	0·125	0·0625	0·0625
Driving wheels, in inches.	0·09375	0·125	0·1.5	0·09375	0·0625	0·125	0·0625	0·0625
Trailing wheels, in inches	0·09375	0·09375	0·125	0·09375	0 06·5	0·125	0·0625	0·06·5
Swing motion trucks, in inches	3·125	3·125	(1)	3 125	(1)	(1)	2·1875	2·1375
Radial trucks, in inches	...	...	...	...	...	...	...	...
C. Radius, in feet, of sharpest curve over which the locomotive will operate.	320	303	206	360	321	400	325	325
V. Lubricating appliances :								
A. Are "Centrally located" lubricators used for various groups of movable parts :								
Cylinders	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Air pump	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Running gear.	No.	No.	No.	No.	No.	No.	No.	No.

A. Is it considered necessary to apply brakes to all or only a part of the wheels of high speed locomotives :	All.	All.	All.	All.	All.	All.	All.	All.
B. Percentage of braking power used in reference to total weight in working order.	...	...	...	...	...	...	...	...
a) On the locomotive wheels	63·3	63·3	57·7	60·0	75·0	51·0	59·5	59·5
b) On the tender wheels.	49·2	39·5	51·6	39·5	34·0	39·5	35·0	35·0
VII. Miscellaneous. To include description of any special construction used for running or driving gears on locomotives built for high speed service :								
A. Locomotive only	None.	None.	None.	None.	None.	None.	None.	None.
B. Tender only	None.	None.	None.	None.	None.	None.	None.	None.
Question VII.								
Fuel.								
I. Is fuel used for high speed service :								
A superior quality	No.	No.	No.	No.	No.	No.	No.	No.
Or ordinary grade	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
II. Analysis and heat producing power of fuel used :								
Combined moisture, in percentage.	3·10	5·10	2·12	3·50	5·63	2·0	12.0	12·0
Volatile combustible, in percentage	41·25	41·25	39·40	40·90	42·62	40·00	32·00	32·00
Fixed carbon, in percentage.	45·35	45·35	46·26	43·95	42·71	50·00	46·00	46·00
Ash, in percentage	10·30	10·30	12·20	11·65	8·99	8·00	7·60	7·60
Sulphur, in percentage	3·45	3·45	4·27	3·95	3·72	4·00	2·50	2·50
Heat producing power, British thermal units	13,400	13,400	13,500	13,300	13,340	12,000	11,500	11,500
Question VIII.								
Trial results.								
Data secured from service records.	None.	None.	None.	None.	None.	None.	...	None.
Consumption of water, in lb.	...	...	...	...	...	...	5·97	...
— of fuel, in lb.	...	...	...	...	...	...	1·00	...
— of lubricants, in gallons	...	...	...	...	...	...	...	...

(1) Indicates no information furnished.

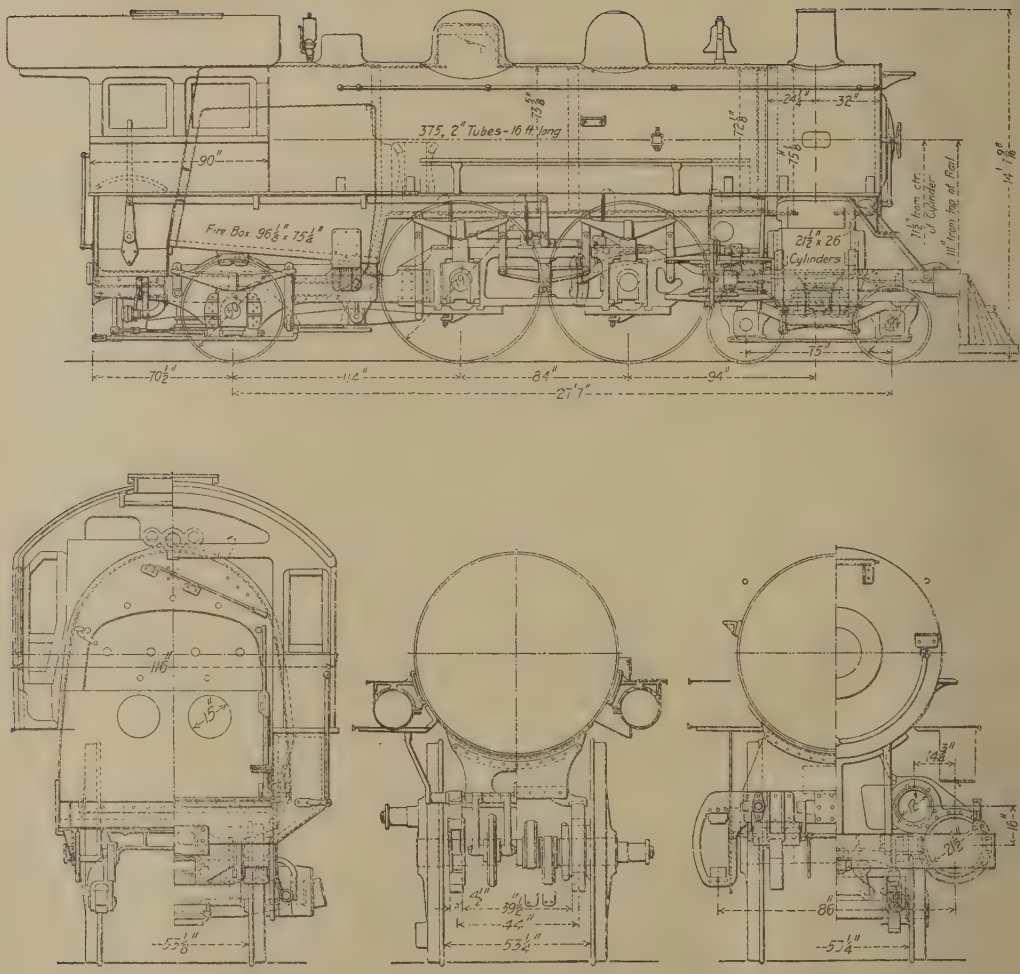

Fig. 1. — New York Central and Hudson River Railroad Division of New York Central Lines. Class IL *Atlantic* or 4-4-2 type locomotive.

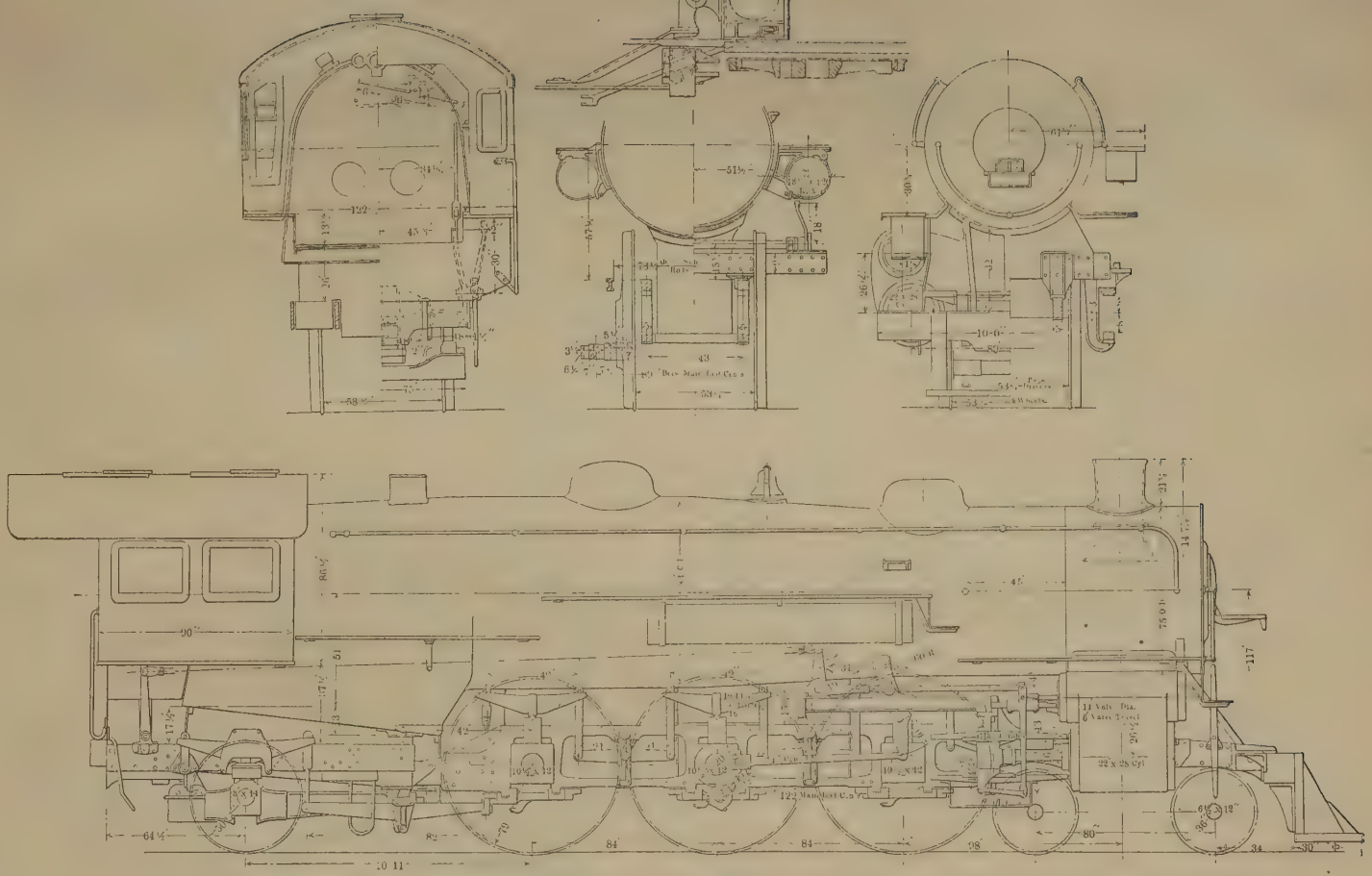

Fig. 2. — New York Central & Hudson River Railroad and Lake Shore & Michigan Southern Railway Divisions of New York Central Lines.
Class K_{2E} *Pacific* or 4-6-2 type locomotive.

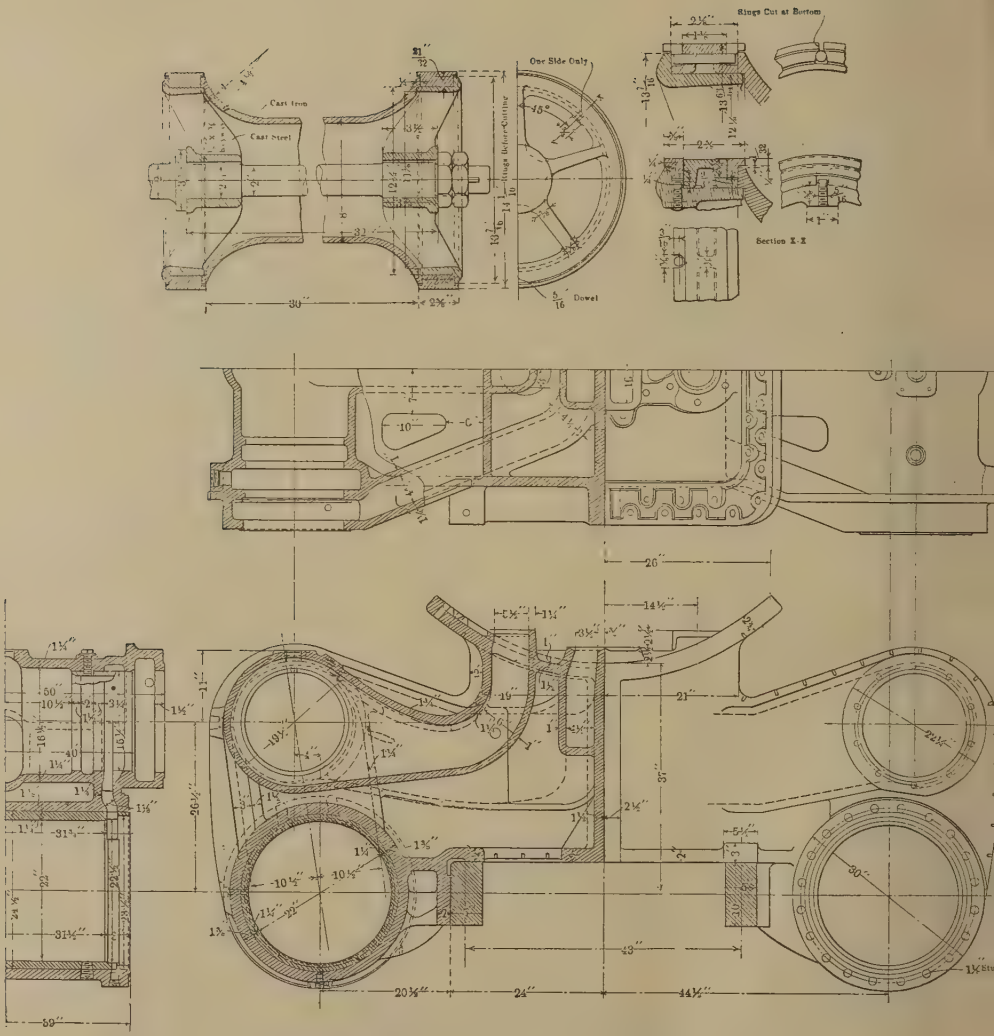

Fig. 3. — New York Central & Hudson River Railroad Division of New York Central Lines.

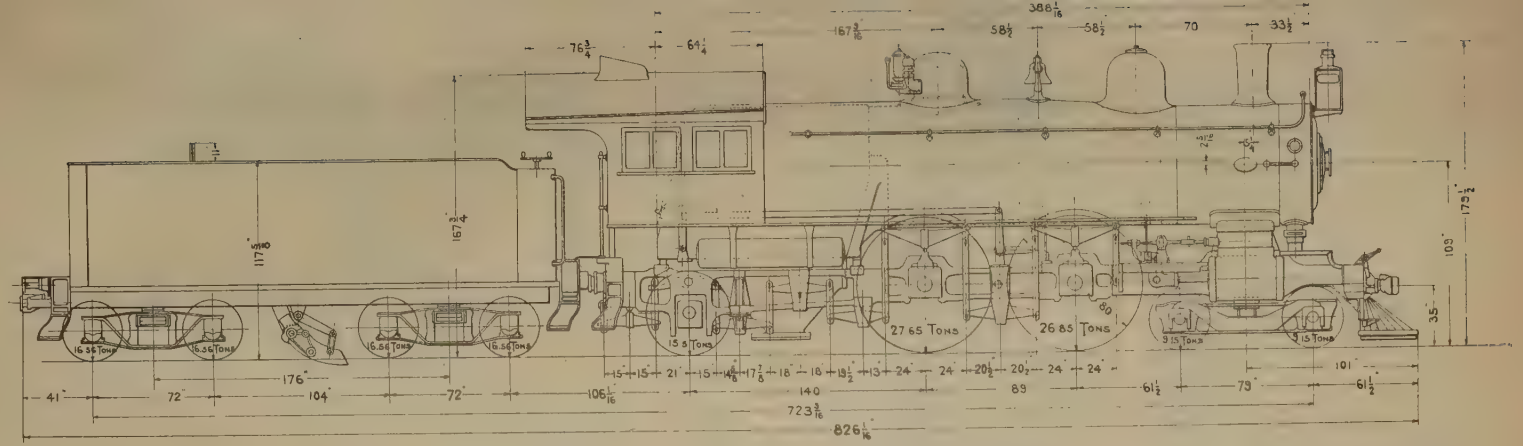

Fig. 4. — Pennsylvania Railroad Company. — Class E_2 locomotive.

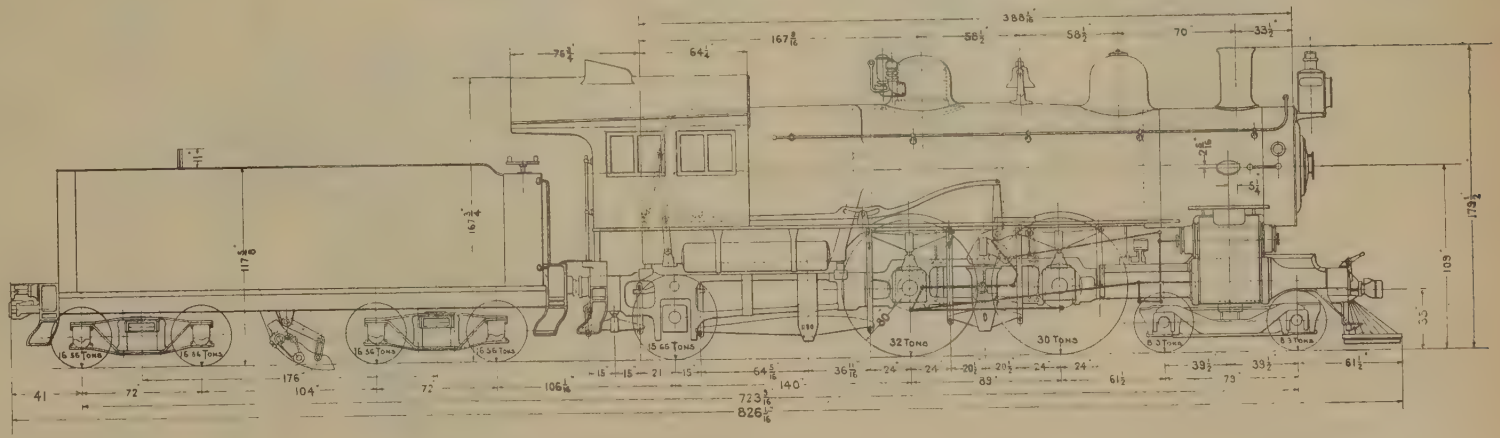

Fig. 5. — Pennsylvania Railroad Company. — Class E_{3D} locomotive.

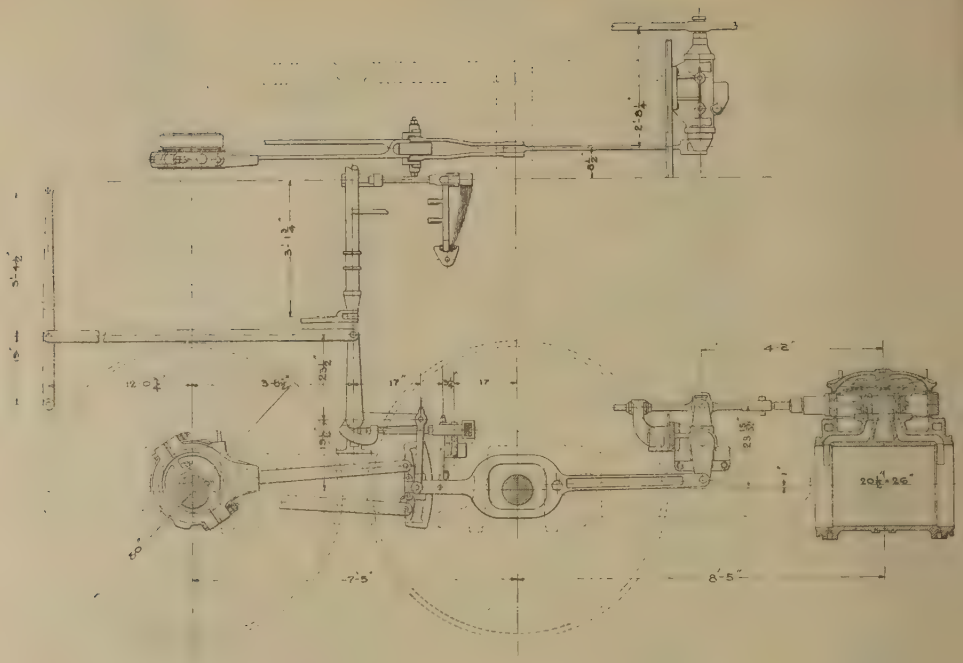

Fig. 6. — Pennsylvania Railroad Company. — Stephenson valve motion for locomotives class E_2, E_{2A}, E_3, E_{3A}.

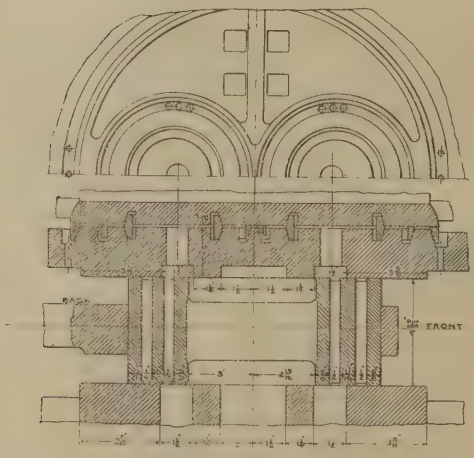

Fig. 7. — Pennsylvania Railroad Company. — Wilson balanced slide valve for locomotives class E_2, E_{2A}. E^3. E_{3A}.

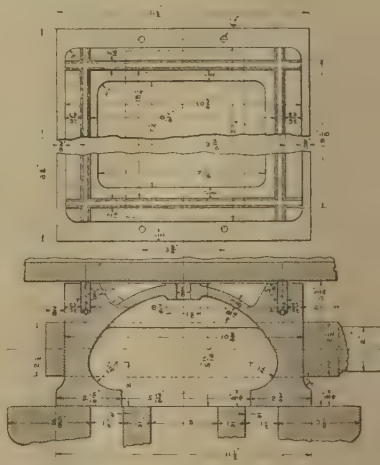

Fig. 8. — Pennsylvania Railroad Company. Richardson slide valve for locomotives class E_{2A}, E_3, E_{3A}.

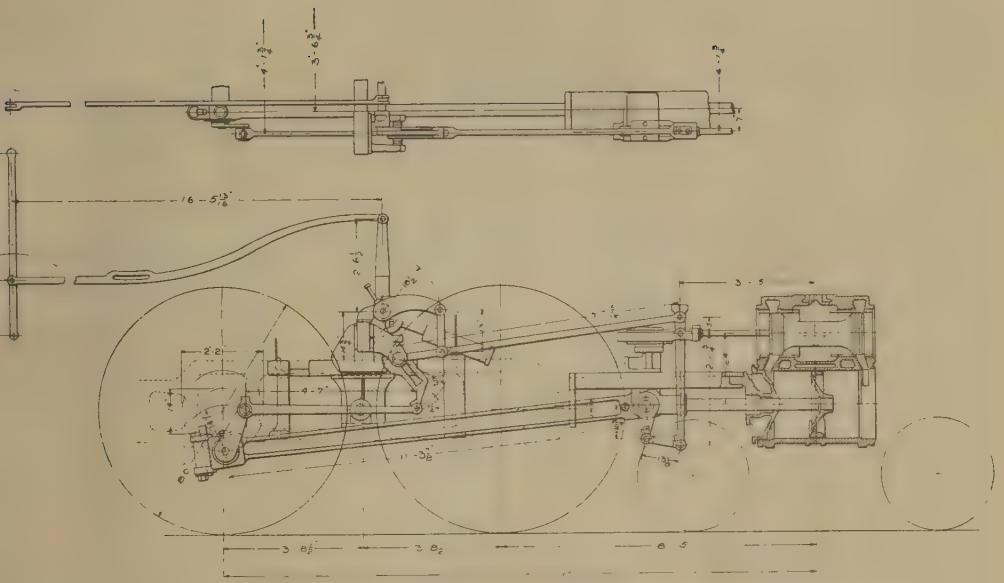

Fig. 9. — Pennsylvania Railroad Company. Walschaerts valve motion for locomotives class E_{2D}, E_{3D}.

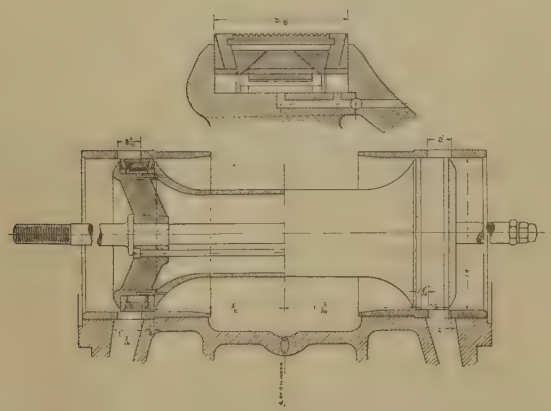

Fig. 10. — Pennsylvania Railroad Company. — Wilson semi-plug piston valve for locomotives class E_{2D}, E_{3D}.

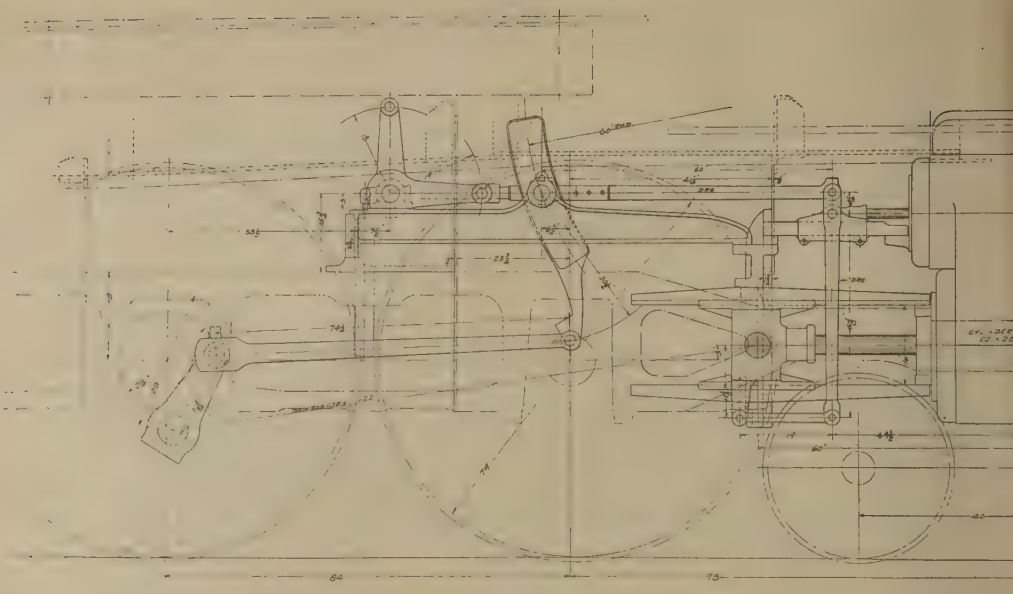

Fig. 11.

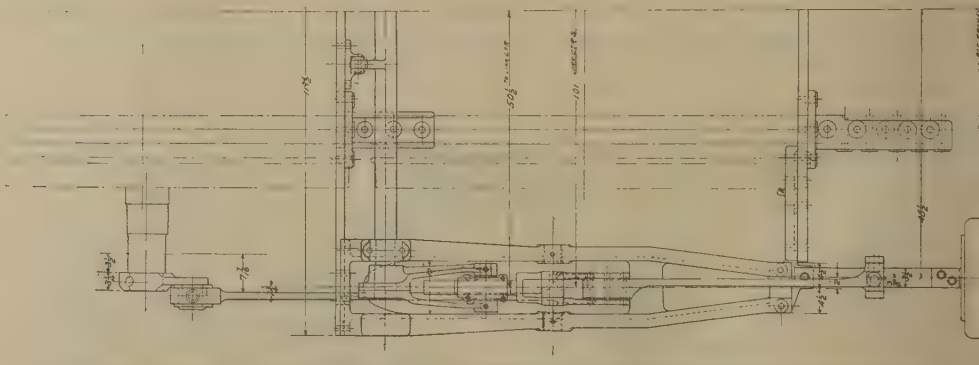

Fig. 12. — New York Central & Hudson River Railroad and Lake Shore & Michigan Southern Railways Divisions of New York Central Lines.

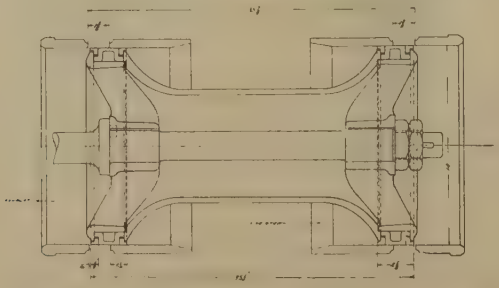

Fig. 13. — Lake Shore & Michigan Southern Railway Division of New-York Central Lines. — Class 462 engines.

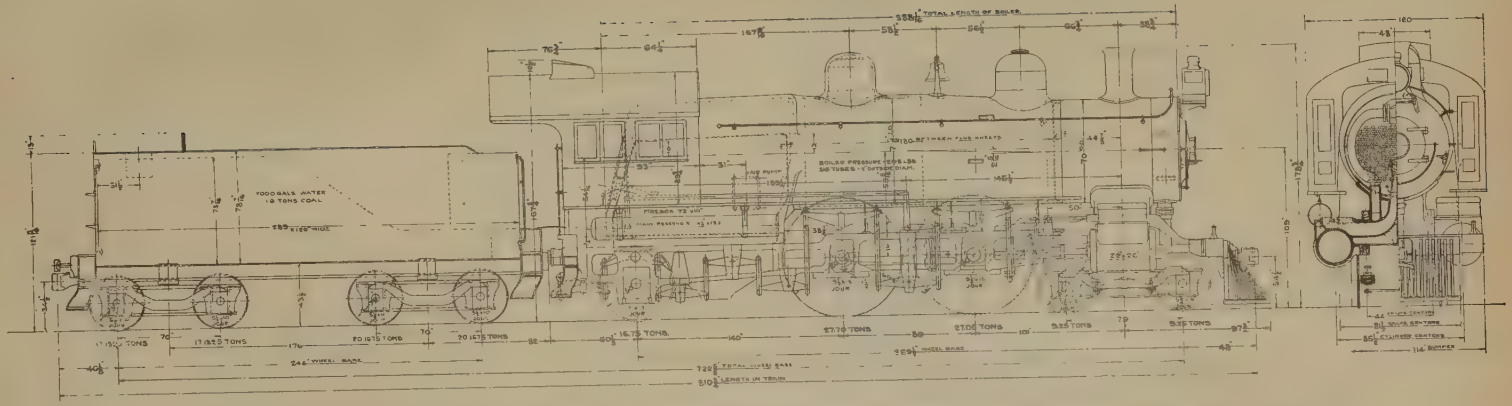

Fig. 14. — Baltimore & Ohio Railroad Company. — *Atlantic* type. — High speed express passenger locomotive. First built, June 1903.

Weight of engine	90·0 tons.
Weight of tender	74·7 —
Total weight. . .	164·7 tons.

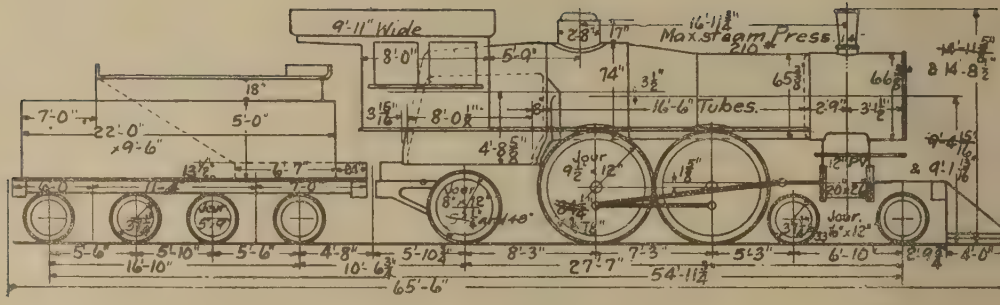

Fig. 15. — Chicago, Burlington & Quincy Railroad.

Boiler. — radial stay :

Fire-box : 66 1/4 inches W × 96 1/8 inches L.
Tubes : 330-2 inches D. D.

Heating surface :

Fire-box	155·5	square feet.
Tubes	2,834·5	—
Total	2,990·0	—
Grate area	44·1	—

Tractive power :

84 1/4 inch drivers	22,000	lb.
78 inch —	23,800	—

Weight on drivers :

Weight on front drivers	44,75
— on main	46,50
— on total	91,25
— on lead truck	46,50
— on trail truck	49,25
— total of engine	187,00

Weight of tender :

Empty	46,40
Water : 6,000 gallons	50,00
Coal : 12 tons	24,00
Total	120,40
Weight of engine and tender in working order	307,40

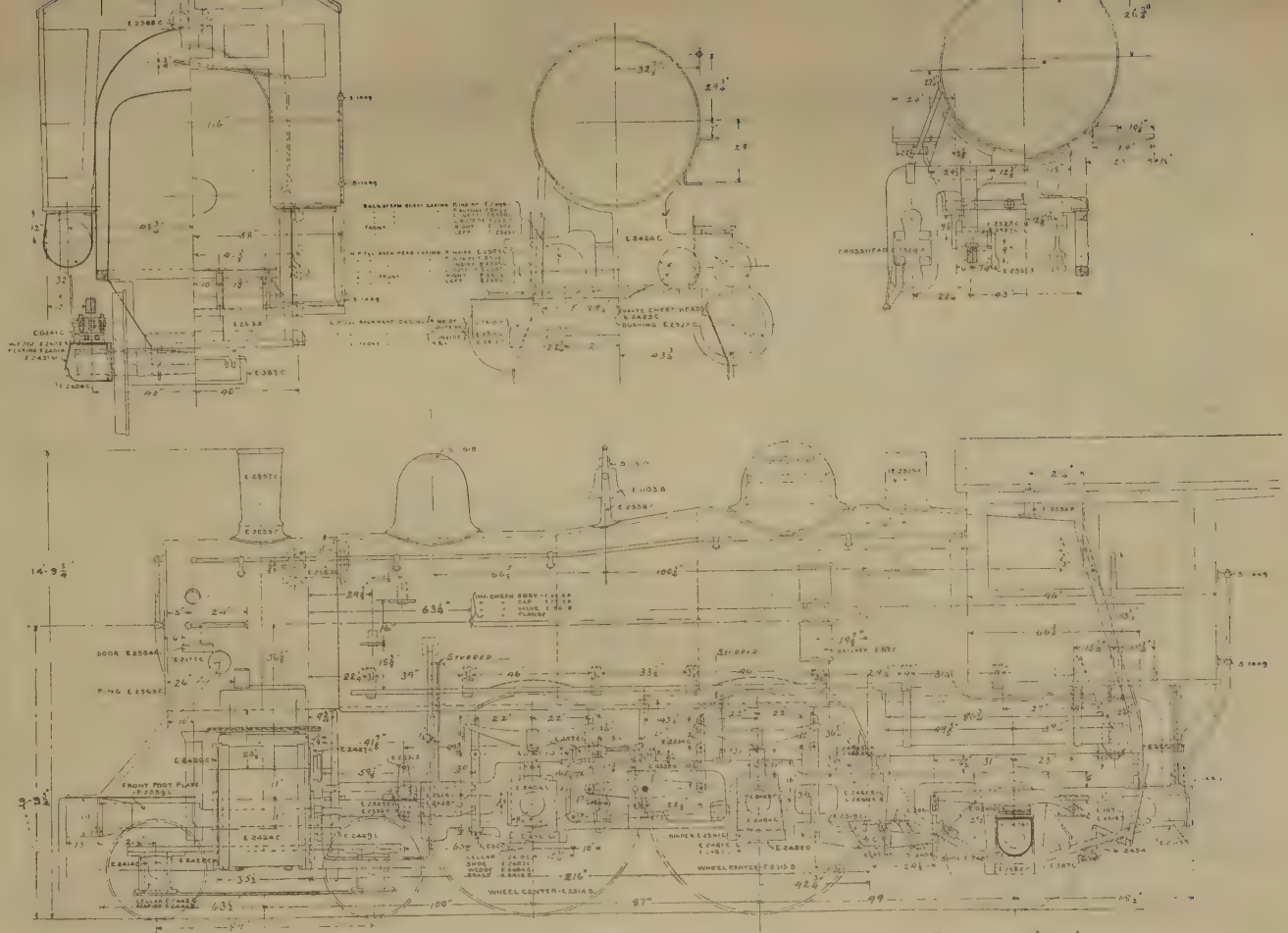

Fig. 16. — Chicago, Burlington & Quincy Railroad. — Elevation and cross sections. — P2 compound engine.

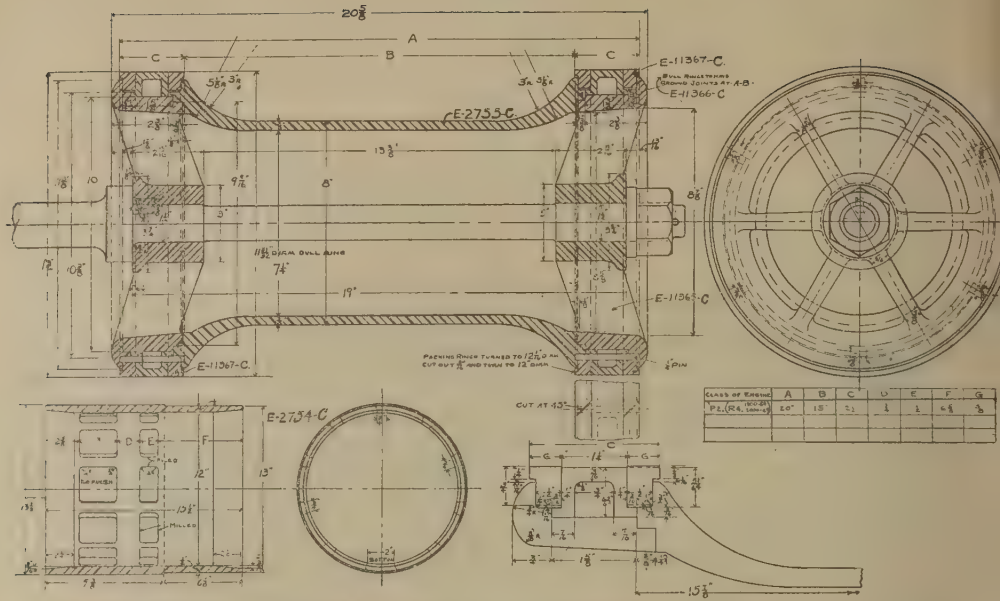

Fig. 17. — Chicago, Burlington & Quincy Railroad. — 12 inch piston valve & bushing. — P_2 simple engine.

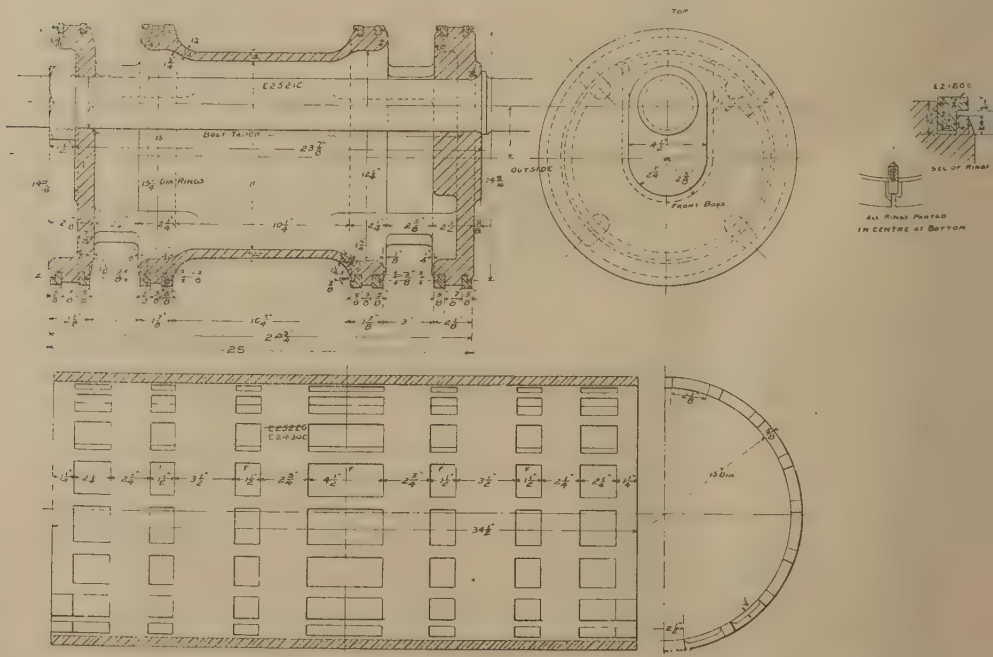

Fig. 18. — Chicago, Burlington & Quincy Railroad. — 15 inch piston valve & bushing. — P_2 compound engine.

The foregoing covers replies from six large Railway Systems in the United States and is subdivided to cover eight classes of locomotives which however are embraced in but two general types so far as their design is concerned. In American Railway Circles, these types are commonly called *Atlantic* and *Pacific* and are otherwise known by the designations 4-4-2 and 4-6-2 respectively, this style of designation indicating the wheel arrangement under the locomotive proper, and is explained as follows : the first numeral, indicates the number of wheels in the leading truck, the second numeral, the number of driving wheels and the last, the total number of wheels in the trailing truck. It will be noted that of the eight classes reported, six are of the 4-4-2 and two of the 4-6-2 type; that all use "Non-superheated Steam" and but one (of the 4-4-2 type) is compounded. It will be further noted that all but two classes use piston slide valves for distribution of steam to cylinders, and the motion controlling the valve operation is of the Stephenson shifting link type for all of the 4-4-2, and of the Walschaerts stationary link constant lead type for the 4-6-2 locomotives.

It will be noted that with the exception of the 4-6-2 type, the stroke common to all the engines is 26 inches, the 4-6-2 having a 28 inch stroke. With the exception of the compound (last column), all of the 4-4-2 type have cylinders varying from 20 to 21 inches in diameter and for the 4-6-2 the cylinders have a diameter of 22 inches.

Working pressures vary from 185 to 210 lb. by gauge or 200 to 225 lb. absolute, the general range varying from 200 to 205 lb. gauge pressure.

The driving wheels vary from 78 to 80 inches in outside diameter, and the weights (of the locomotive only) in working order from 90 to 95 tons for the 4-4-2, and 131 to 133 tons for the 4-6-2 type, the weight on driving wheels varying from 45·6 to 59·17 tons for the 4-4-2 and averaging 86·00 tons for the 4-6-2 types.

An interesting study may be drawn from averages of the different important items embraced in the tables covering the primary characteristics of the engines reported, by grouping and averaging the replies for the 4-4-2 and the 4-6-2 types separately, omitting the compound (as per last colum), and by doing this a composite result is attained which embraces an average of all designs, that are now in use in the service falling within the scope of our question, and the following is drawn on these lines for the benefit of the Congress.

General name of class	*Atlantic.*	*Pacific.*
Wheel distribution (locomotive only)	4-4-2	4 6-2
Weight on driving wheels, working order, in tons	53·234	85·875
Working pressure, by gauge, in lb.	201	200
Diameter of cylinders (high pressure), in inches.	21	22
Stroke of cylinders, in inches	26	28
Type of valve used for steam distribution	Piston.	Piston.
— of valve gearing	Stephenson.	Walschaerts
Diameter of driving wheels, outside, in inches	79·2	79

	Atlantic.	*Pacific.*
Total tractive force, in lb.	24,268·0	29,900·0
— heating surface, in square feet	2,948·2	4,192·0
Grate area, in square feet	51·1	56·6
Ratio of total heating surface to grate area	58·33 to 1·00	74·10 to 1·00
Ratio of heating surface to cylinder volume	512 to 1·00	342 to 1·00
Capacity of tender for water, in gallons	6,700	8,000
Average speed required to maintain schedules, in miles	55·26	55·85
— weight of trains, in tons	344·88	452·00
— number miles made without stops	100·00	160·40

Laboratory Tests of Locomotives in America have been very extensive, and there are now two complete Plants prepared for the reception of the largest machines and a great number of tests have been run on these Plants with different designs of locomotives to determine all critical points and give the Designer full benefit of the factors necessary to produce the highest efficiency.

These Plants are located at Purdue University, La Fayette, Ind., and the Shops of the Pennsylvania Railroad at Altoona, Pa. Both have been largely instrumental in producing reliable data governing the factors to be recognized in designing a locomotive for the highest efficiency, therefore an average of the deductions obtained deserve prominence in consideration of the subject at issue and a summary of these averaged conclusions follows :

Boiler performance.

Boiler horse-power per square feet of heating surface	0·40
Weight of steam delivered, per hour, per square feet of heating surface in lb.	14·00
Per cent moisture in steam delivered	1·35
Maximum economical pressure for saturated steam, in lb. by gauge	200·00
Maximum evaporative efficiency, water per pound of coal, when power developed is low, in lb.	11 00 .
Evaporative efficienoy, water per lb., of dry coal, when the power developed is greatest, in lb.	7·00
Fire-box temperatures, degrees Fahrenheit at low rates of combustion	1,400 to 2,000
— — — — at high rate of combustion	2,100 to 2,300

Cylinder performance.

(High-pressure only.)

Steam consumption per indicated horse-power, per hour, average minimum, no superheat, in lb.	24·35
Steam consumption per indicated horse-power, per hour, average maximum, no superheat, in lb.	24·40
Percentage of cylinder power appearing as a stress at drawbar, at 40 rev's per minute	86·00
Percentage of cylinder power appearing as a stress at drawbar, at 280 rev's per minute	75·00
Piston speed, feet per minute, at which wire-drawing of steam begins.	800·00

	Ratios.
Heating surface to grate area	56 to *72 to 1·00
— — to cylinder volume	275 to *350 to 1·00
Tractive effort to heating surface	8·60 to *8·29 to 1·00
— — to weight on drivers	4·36 to *4·66 to 1·00
Weight on drivers to total heating surface	37·5 to *38·6 to 1·00
Grate area to cylinder volume	4·85 to *4·27 to 1·00

It is to be regretted that no conclusions have been reached by these Testing Plants to demonstrate the superiority of either the Piston or the Flat type of slide valve also the relative merits of the shifting link or Stephenson type of valve gearing as opposed to the stationary link constant lead gear on the Walschaerts principle, as there is a marked tendency on the part of some American Designers to use the latter in recent constructions notwithstanding the fact that all but two of the classes of engines reported have their valves operated by the Stephenson shifting link gear. In the opinion of the writer, the Walschaerts principle can be commended solely from the standpoint of easy inspection and maintenance, and not for superiority in steam distribution. Locomotives in America are designed for all round service, but are necessarily districted to either the Passenger or Freight Department and any one of the modern power in either Department can be called upon and is regularly used on a great majority of the Railroads, in what might be termed an alternating service, that is, such a locomotive might be employed to transport trains at high speeds in one direction over a Division and its return trip frequently is in local service, this state of affairs requires the locomotive to be run at constantly varying piston speeds and it is a well known fact in the writer's judgment that constant lead valve gears are not adapted to these variations of piston speeds. Shifting link valve gears of the Stephenson type, while it has inherent defects, readily adapts itself to variable piston speeds in such a manner that in the opinion of the writer, it will give considerable better service from a standpoint of steam distribution than the Walschaerts since the latter is an invariable quantity so far as angular advance necessary to the higher piston speeds is concerned.

Limiting factors in the design of locomotives used in America today have been "Clearances along the line of permanent way and in Terminals and running load per foot on bridge panels", and as the primary factor in the capacity of a locomotive

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* Indicates ratios for *Pacific* or 4-6-2 type only, others are for *Atlantic* or 4-4-2 type.

lies in boiler duty, it became necessary to largely increase the heating surface and coincidently the grate area above the Pioneer or 4-4-0 engine, commonly called the American type. Logically the *Atlantic* or 4-4-2 type resulted, since the longer boiler and large overhanging fire-box required the introduction of a pair of trailing wheels, the weight on which is equalized with the weight on the driving wheels rendering it possible to provide greater weight for adhesion without exceeding the limits permissible on bridge structures. This permitted the use of larger cylinders which the increased capacity of the boiler was able to supply. The trailing trucks used are of three general types, which are again subdivided into two classes, and can be called either outside or inside bearing. The outside bearing type is always designed with an independant frame which is fulcrumed to the main frame of the engine by a radius bar or tongue, and the overhanging weight supported by this truck is free to move latterally in either direction by means of rollers on which the supporting springs rest. One of the inside bearing types is a modification of the or english *Ramsbottom* type having a radial box working in jaws of the main frame, the journal box proper working inside of the radial box. The lateral movement is controlled by duplicate springs working in a casing at the center of the engine frame and these can be adjusted to suit requirements.

The other inside bearing type is simply an adaptation of the usual construction used with bar frames for driving boxes, with the exception that a somewhat increased lateral movement is provided between the flanges of the boxes and the frames and at the hubs of the wheels to provide for lateral oscillation.

The *Atlantic* or 4-4-2 type of locomotive in Express service today in America vary considerably in total wheel base, the principal difference being in the distance from the center of the trailing wheel to the center of the nearest driving wheel, it being understood that the diameters of the driving wheels themselves regulate the rigid wheel base, consequently, considerable variations in the lateral swing provided in the trailing trucks becomes a necessity and must be governed by the wheel base.

The *Pacific* or 4-6-2 type of locomotives is a modification of the *Atlantic* in the single feature of adding one more pair of driving wheels to accomodate a still larger boiler and cylinders and provide the necessary weight for adhesion. Developments of the *Pacific* type locomotive in its most recent form appear as the 4-6-2 type credited to the New York Central & Hudson River Railroad, and Lake Shore & Michigan Southern Railway in the tabled portion of this paper and the large boiler power and reserve capacity as compared with the trains reported will be readily noted and it might be well to say that on numerous occasions special performances of these locomotives have largely exceeded the scheduled results to which this paper has been confined.

The locomotives reported in the table have boilers varying in diameter from 64 to 70 5/8 inches at the outside of the smallest or front course and are of the radial stay extended wagon top, radial stay straight top, also the Belpaire type, and are built of steel plate, all courses having butt joints with inside and outside welt straps sextuple

riveted for the horizontal seams, and double riveted for circumferential seams. These boilers have fire boxes constructed of steel plate and the fire tubes are what is known as high grade charcoal iron or of mild steel. All tubes are cylindrical in section and have no ribs or projections to increase heating surface following the lines of the Serve tube with which the boilers of some of the European locomotives are equipped. None of the boilers in the locomotives reported, have combustion chambers although a few of the 4-6-2 type in use on the Lake Shore & Michigan Southern Railway are so equipped for experimental purposes.

The frames are all of the bar section throughout the main portion and have the pedestal jaws forged solid, the main sections running continuously from the back transverse walls of the cylinders to the extreme rear of the machine in most cases. The front splices, over and under the cylinder saddle change from the bar to the slab form to suit the design of cylinders used. These frames are forged from a high grade wrought iron or are cast from Manganese steels and in some of the most recent constructions Vanadium steel has been used. It is the practice in America to confine machine work to the minimum and with that in view to reduce cost machining is confined to bearing points and bolting surfaces only, leaving the remaining portions rough except at such points where a smooth finish would contribute to better appearance.

Cylinder castings, are almost universally made reversible for use on either the right or left side on the locomotive and as practically all are built for outside coupling, they are in the majority of cases cast solid with one half of the saddle, making a bolting face in a vertical plane on the longitudinal center line. Cylinders in the majority of cases are made of a superior quality of cast iron as hard as can be successfully machined, the object of the latter being to reduce wear to the minimum in main bores, valve chambers and seats. More recent practice in the larger equipment has been to use cast steel cylinders, especially for piston valve engines, the main bore and valve chambers of which are fitted with cast iron bushings for successful operation. Piston valve cylinders are usually constructed for " Internal Admission ", and all flat slide valve cylinders are arranged for " External Admission ". the latter being caused by the compact form of the valves practically prohibiting proper coring of the ports without resort to an extremely large valve and seat. As a result, friction losses in ports in the piston valve machine are smaller than can be secured with the flat slide valve and an additional gain for the piston valve occurs on account of its location in the cylinder saddle where it is more perfectly insulated against temperature losses. Both classes of cylinders are lubricated by special oils, the automatic feed of which is regulated by needle valves of " Sight Feed Lubricators " located in the cab and directly under the control of the Engineman, these lubricators generally being of the triplex form, one part of which feeds the air pump and the other two feeding the right and left hand cylinders independently, the oil in its passage being introduced to the valve chamber and volatilized by induction steam and in this form reaches every moving part. The

cylinders are provided, in the majority of cases, with a relief valve applied to the induction steam passage through the exterior saddle walls at a point close to the valve chamber and the function of this valve is to automatically relieve a vacuum when drifting and it also partially guards against movement of the locomotive from throttle leakage when left standing unprotected by a crew. Drain valves are always provided to relieve the main bore, valve chambers and the saddle induction cores from condensation or from priming and are attached to the lowest portions of these parts in order to entirely relieve them of such water. These drains are not automatic but are under the control of the Enginemen and are operated from the cab by a hand lever.

The main valves, of the " Piston Type " are generally of the elongated spool form, the central portion being cast in one piece and the ends fitted with independent heads to provide a means of applying the packing with usually consists of a main ring, commonly called a Bull or Tee Ring, the main section of which is made sufficiently wide to suit the width of the ports across which it will operate and this main ring is fitted with either " Split " spring rings of rectangular form, or sectional " L " shaped main rings backed up by square section rings which are divided into the same number of parts as the " L " rings, the latter style of packing requires a flat steel spring between the under surface of the packing rings proper and the Bull Ring flange to keep the rings in their proper position when the locomotive is not using steam, but it must be understood that both of these forms of packing are made tight by steam pressure only and do not depend on auxiliary springs or the spring character of the ring itself to make the packing tight. Valves operated by the Stephenson shifting link gear, are coupled to either " Direct " or " Indirect " forms of this gear according to the will of the designer, although the position of the valve in the cylinder saddle usually determines that piston valves shall be coupled to the direct form of gear as opposed to flat slide valves whose position practically forces indirect coupling. Piston valves by reason of their design are totally balanced against the opposing pressures, whereas flat slide valves, by reason of their form, and the fact that the flow of steam from induction to release is entirely controlled by the lower face of the valve, cannot be balanced in excess of 65 percent of the total area of the valve face as found by multiplying the length by the width without regard to the area of any cavities which may appear in the lower valve face. Flat slide valves are of two general forms, that is, the plain and the doubleported types, the latter being arranged with a narrow cavity usually $^1/_2$ inches in thickness of core, the total width of the core approximating 80 percent of the length of the cylinder steam port, and the function of this cavity is to multiply the induction of steam to the cylinder by permitting steam to flow through same at the instant the cylinder port commences to admit steam over the main edge of the valve, and to do this the valve seat of the cylinder must be designed of a proper width to suit such a form and extra care must be used in the design to prevent over-reaching at point of extreme travel to prevent blowing. The use of the Steam Engine Indicator on locomotives in regular service,

has, in the writer's judgment, thoroughly demonstrated that a port opening for admission, amounting to 0·25 inch at the extreme ends of the stroke, been found ample to supply steam at most economical points of cut-off and high piston speeds, although 0·3125 inch undoubtedly would be more advantageous in preventing wire-drawing, and to secure this opening, which in America is usually termed " Mid-Gear Lead " resort must be made, when using the Stephenson shifting link gear, *to " Negative " lead in backward motion at full stroke*, and the amount of negative lead must be governed by the stroke of the engine on which it is used as its purpose is to reduce " pre-admission " to the minimum in order to provide the necessary mid-gear lead above referred to. This applies alike to all Stephenson shifting link gears irrespective of whether the motion is coupled direct or indirect or whether the valves are of the flat slide or the Piston type. Locomotives for high piston speeds should have all counter-pressures eliminated to the greatest possible extent and with pre-admission beginning at a point not greater than 1 inch before the end of the stroke is reached, and release occuring after the crank pin has traversed not to exceed 135 degrees of its path, the most advantageous conditions are obtained, and to this end, " Exhaust Clearance " must be resorted to, and the amount of such clearance is to be entirely regulated by the valve travel and stroke of the engine. Constant lead gears with stationary links on the Walschaerts principle and designed for high speed locomotives, must necessarily provide the same conditions as noted above and if possibilities of design will admit of these conditions, then no further comment is necessary from a standpoint of criticism of the Walschaerts type except to say that it is deficient in meeting the most consistent requirements of variations in piston speeds over or under that particular speed for which the motion is primarily designed.

American locomotives, irrespective of class, with the exception of a few experimental machines, have outside cylinders only and no crank axles. The driving wheels of the most modern machine, have centers of cast steel that are hydraulically forced onto steel axles and fitted with proper keys, and these wheel centers are fitted with hard rolled-steel tires secured by shrinkage only or by shrinkage and retaining ring fastenings and in the 4-4-2 and 4-6-2 types, all driving tires are flanged. Crank pins are hydraulically forced into the wheel centres and riveted over on the inside face of the crank pin hub, the wheels being quartered after being pressed on the axles in order to insure one engine being 90 degrees in advance of its mate and it is customary to lead the right hand engine. Fiber-stresses in steel axles and crank pins in the most modern practice are designed *not to exceed 18,000 lb. at the minimum diameter of limit of wear* and to insure against failure from hot journals, the practice has been toward the introduction of hard grease lubrication of these journals notwithstanding it is a conceded fact that grease lubrication increases the machinery friction approximately 25 to 30 per cent over oil. The introduction of grease lubrication has made *long high speed runs without stops* entirely safe and consistent without resort to the use of auxiliary lubrication from

centrally located sources of supply which would have been necessary had the use of oil been continued. Journal boxes for driving wheels are usually constructed of cast steel with high grade bronze bearings of crescent form pressed in, and the pedestal fit of the boxes are frequently faced with anti-friction metal to reduce scoring against the shoe and the adjustable wedge faces, the latter being provided to take up wear and keep the position of the wheels of a uniform spread to reduce strains in coupling rods. In the 4-4-2 type, the main driving wheel is always at the rear and in the 4-6-2 type, it is always the second wheel and the coupling rods, in the latter class, are always provided with a knuckle joint at the rear of the main crank pin journal to provide flexibility against the independent rise and fall of the wheels due to inequalities in surfacing of track. Coupling rods are usually forged of steel and have solid ends fitted with bronze bushings and in their design compression and whip strains from centrifugal force form the principal factor, and the eye beam section is customarily resorted to to meet the conditions most ideally. Connecting rods, from the main crank pin to then cross head, usually called the " Main Rod " in America, are also forged of steel, but are provided with sectional journal boxes at each end to permit of adjustment, these are also designed to meet compression and whip strains similar to the coupling rods.

Eccentrics, used with the Stephenson Valve Gear, are customarily made of cast iron with a broad wearing face for the eccentric strap seat, the width of the bearing face usually being about 3 inches. Straps for the larger and heavier power are made of cast or malleable iron and of cast steel and the latter are always provided with antifriction metal linings.

A form of eccentric strap, using a loose cast iron ring, which is free to revolve in the strap and around the eccentric, has been placed in service in the last five years and our experience with this form leads us to say that it is the superior of any other that has come to our notice. Eccentric straps in America are usually provided with an oil cup also an independent oiling pipe, the latter being the medium through which the Engineman applies the lubricant when the locomotive has been stopped at Division Stations, the cup forming the main reservoir as a means of slow but continuous oiling on long runs and is usually fed by the vertical throw of the eccentric in its cycle of rotation. It might be well to say at this point that oil is the lubricant employed for the machinery of American Locomotives, the engine truck, driving and trailing axle journals and crank pins including the wrist pins which are grease lubricated, excepted, consequently all oil cups or cellars used are packed with curled hair to form a matrix to prevent the oil from throwing out as a result of the movement of the machinery parts and these on the whole have been found to meet the conditions in a generally satisfactory manner and no attempt is being made to substitute centrally located oil reservoirs in their stead.

The writer has never been a believer in the necessity of special designs or constructions to suit the requirements of high speed service of locomotives, regardless of whether the runs were comparatively short or were long sustained, and as a proof

of the accuracy of this position, countless instances are under our very eyes if the trouble is taken to glance over the practice used in stationary engines, where speeds as high as 300 to 350 rev's per minute are maintained continuously for six, eight and twelve hours service especially at central stations where electric power is generated, and where it will be found that no special change in design has been made to suit the high speed service, except to improve the governor design so as to make it more sensitive for the proper control of the machine. As a consequence, the writer has always employed the same standards on the various classes of locomotives built under his jurisdiction, for the sake of reduction in the number of repair parts to be kept in stock and the additional advantage of easy and quick repair in emergency cases, and we therefore believe that with valve motion and all running parts constructed along standard lines and carefully assembled, that the secret of success of locomotives used on long sustained, high speed runs, lies in boiler capacity and the ability of the crew handling the machine to secure the highest boiler efficiency at the expenditure of the least fuel, since accumulated refuse on the grates, due to a heavy consumption of fuel per square foot of grate per hour, cannot be successfully disposed of entirely by shaking the grate, with the result that combustion is retarded due to choking the supply of free air with the result that the boiler duty falls off rapidly and averages considerably below the efficiency it was possible to secure when the fire was cleaned. Feed water and the temperature at which it is supplied to the boiler becomes an important factor in maintaining a high efficiency on long sustained high speed runs and if there is anything to be gained to enhance the possibility of a continuous successful performance of a locomotive on high speed, long distance runs, in the judgment of the writer it lies in the introduction of a successful feed water heater that will deliver water at temperatures of 190° Fahr. or better, the heating to be done by waste steam, and the heater to be used in series with the injector in order to still further raise the temperature of the water delivered by the injector to such a point, that on its introduction to the boiler proper, it will be practically at the boiling point and will not have atendency to cool down the water previously admitted to the boiler. In the judgment of the writer, this will result in an economy in fuel considerably in excess of the advantage said to have been gained by some forms of superheaters without the additional cost and annoyance consequent on the successful maintenance of the latter.

The tenders of American Locomotives almost without exception have two independent four-wheel bogie trucks, pivoted at the center of a floating bolster resting on springs at either end and carried by the truck frame. The journals of these trucks are of the outside bearing type and fitted with the same type and kind of journal bearings, keys and boxes as are used for Freight Equipment Cars, and there is no special change in design of these tender trucks over what is commonly used for high class Freight Equipment Cars, except that the parts are made larger and heavier to suit locomotive tender service.

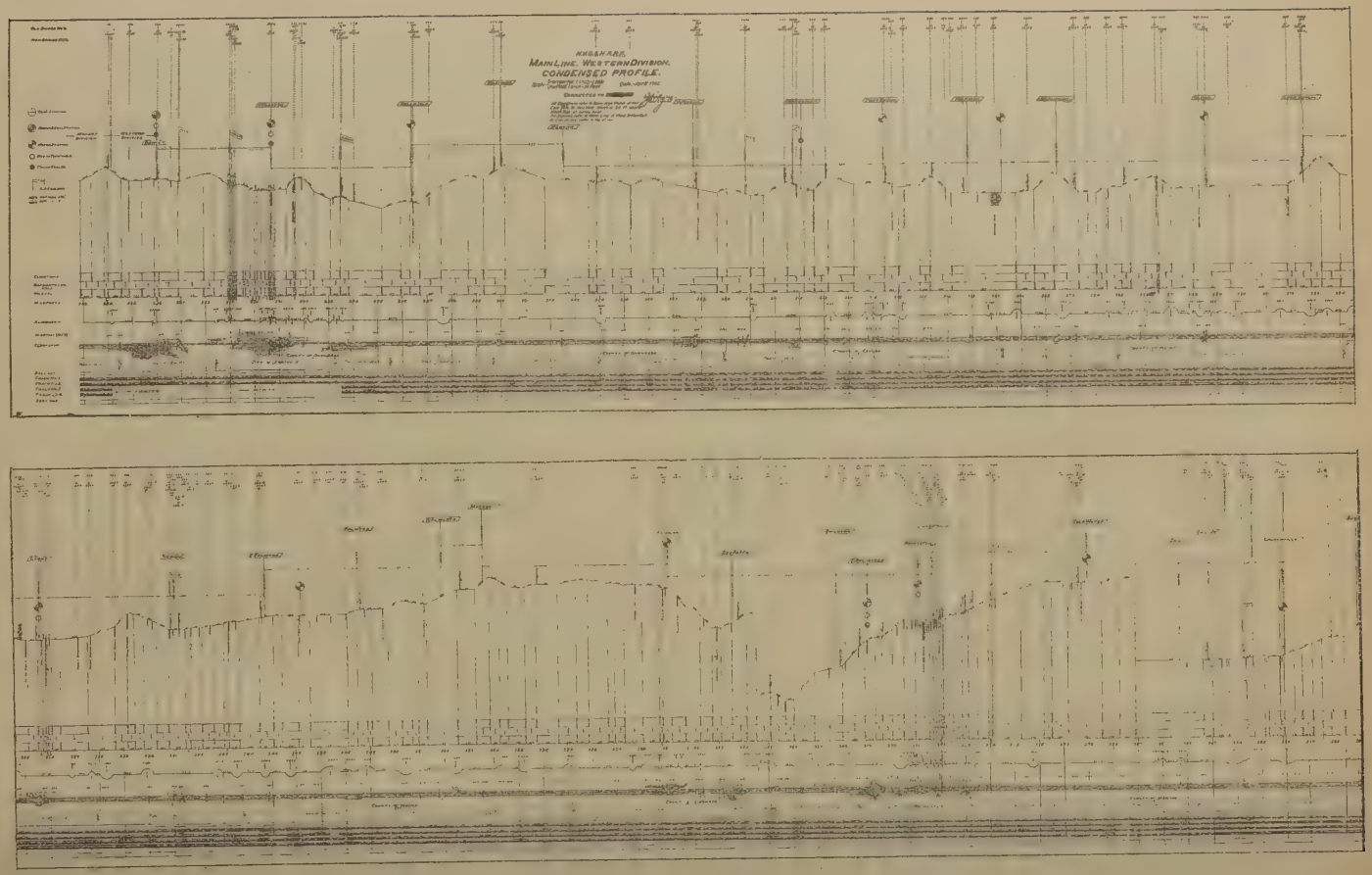


Fig. 19. — New York Central & Hudson River Railroad. — Main line. — Western Division. — Condensed profile.

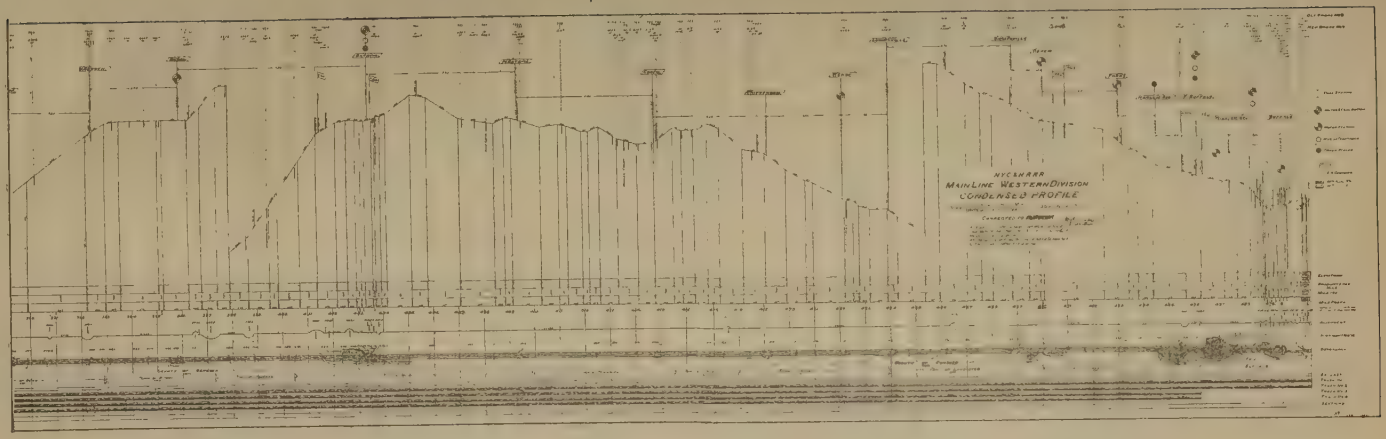


Fig. 19 (*continued*). — New York Central & Hudson River Railroad. — Western Division. — Condensed profile.

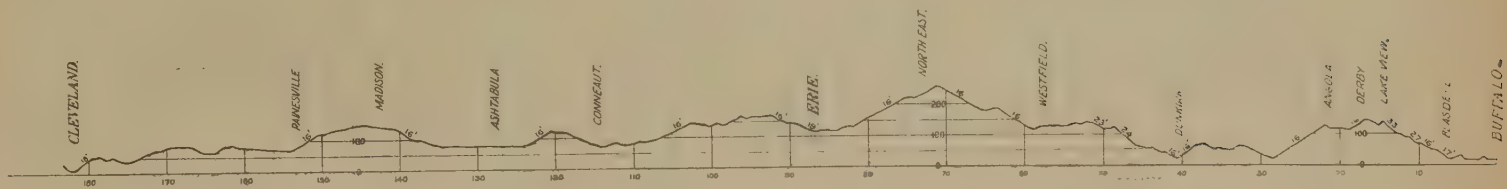


Fig. 20. — Lake Shore & Michigan Southern Railway. — Eastern Division. — Condensed profile.

The Tender Frames of the majority of locomotives now being built in America, are formed of rolled section steel shapes, principally channels and angles and are framed up in rectangular shape and provided with two central longitudinal stiffening members or sills to which the draft attachments are secured and these central members practically form the foundation by which the balance of the frame is supported through the medium of bolsters transversely connecting all parts of the tender frame at a point centrally over each truck. This frame is floored over and the tender cistern proper rests directly on the floor and is secured solidly to the frame. The tender cisterns are built of two types, one called a " Water Bottom ", in which the water space extends full length of the cistern below the coal space, and the other called a " Horse Shoe " Tank in which a coal space is provided full depth of the tank between the side water legs. The Water Bottom type is now being very largely used and particularly lends itself to use on tenders of the 4-4-2 and 4-6-2 types of locomotives, which on account of the trailing wheels have their grates elevated at a considerable distance above the top of the rails and require a " False Deck " as a foot board from which the stoking or firing also the running of the machine is done. All tenders for service behind locomotives for long sustained high speed runs, are equipped with pneumatically operated " Water Scoops " along American modifications of the original English principle, which enables these locomotives to take water at speeds approximating 45 miles per hour, from track tanks in the form of a trough which are usually from 1,000 to 2,000 feet long and located on level tangents. The series of questions covered by the tabulated portion in the first part of this report, did not permit of answers that would thoroughly define the characteristics of the Divisions over which the locomotives reported were running and it has been possible to secure condensed profiles of at least three of the Divisions referred to and we submit a condensed profile of the Main Line of the New York Central & Hudson River Railroad " Western Division " (fig. 19), also of the " Eastern Division " of the Lake Shore & Michigan Southern Railway (fig. 20) and the " Western Division " (Sub-Division C) of the Pennsylvania Lines, Northwest System, and while it is not the purpose of this paper to call attention to special runs, as an exemplification of what it is possible for these locomotives to do, it becomes interesting in connection with the subject to study the profile and the speed curves required to make the high speed schedules a success on such Divisions.

The speed curves of trains 28 and 29 on the Northwest System of the Pennsylvania Lines, shown in figure 21, are from actual records of performances and show the expected performance in daily service required to maintain schedules and it must be remarked that somewhat more than 30 minutes of lost time has been overcome on these trains between Crestline and Ft. Wayne in both directions.

On 28 March, 1909, a special train of four cars, each having six axles, the light weight of the train being 442,700 lb. or 221·35 tons was moved from New York City to Chicago over the New York Central & Hudson River and Lake Shore &

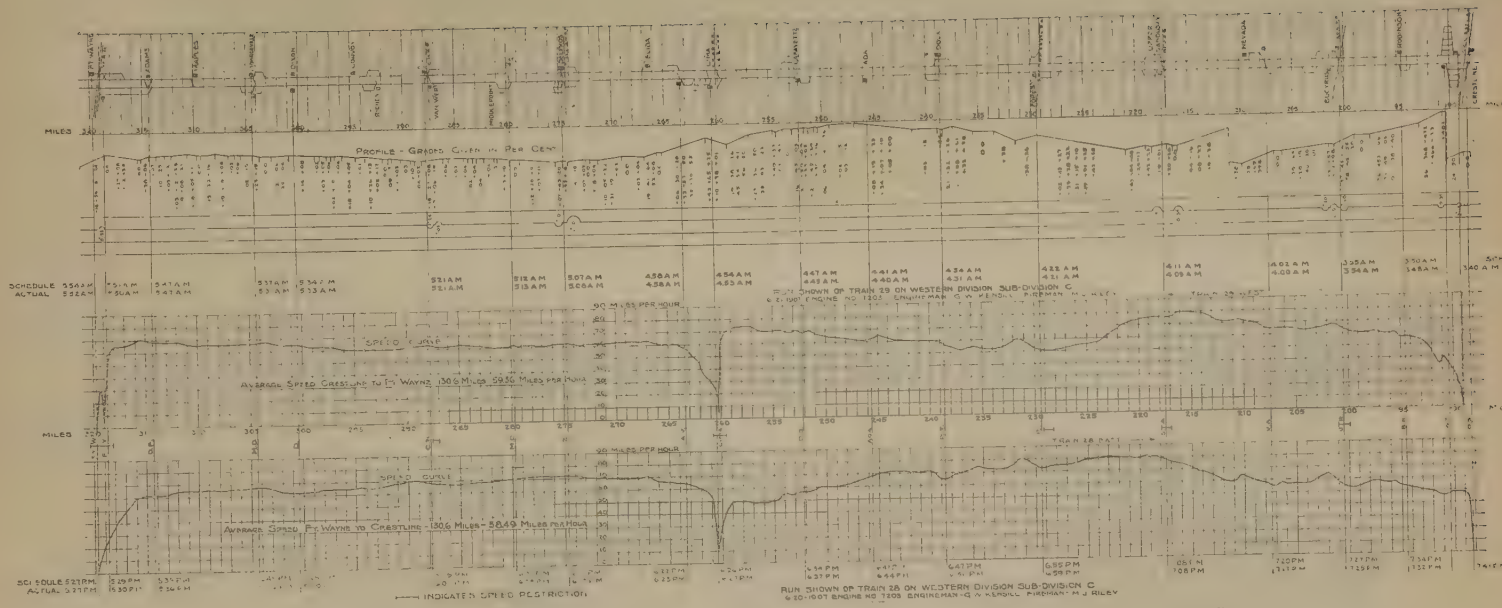

PROFILE - GRADES GIVEN IN PER CENT
SPEED CURVE
AVERAGE SPEED CRESTLINE TO FT WAYNE 130.6 MILES 50.50 MILES PER HOUR
AVERAGE SPEED FT WAYNE TO CRESTLINE 130.6 MILES - 50.49 MILES PER HOUR
INDICATES SPEED RESTRICTION
RUN SHOWN OF TRAIN 29 ON WESTERN DIVISION SUB-DIVISION C
RUN SHOWN OF TRAIN 28 ON WESTERN DIVISION SUB-DIVISION C

Fig. 21. — Speed curves of trains 28 and 29 Pennsylvania Railroad on Western division, sub-division C.

Michigan Southern Divisions of the New York Central Lines, the direction being west, and while there is no special emphasis to be placed on the run on account of the light weight of the train, it enjoys the distinction of being one of the latest runs to be made by the 4-6-2 type of locomotives equipped with Walschaerts Valve Gear owned by the Companies named and we therefore mention the incident as among the easy possibilities. By reference to the figure covering the Western Division of the New York Central & Hudson River Railroad, and bearing in mind the west bound movement, it will be noted that this engine was forced to overcome an elevation of 500 feet in a distance of 39 miles, the average performance over the entire Division being 58·82 miles per hour. This train was turned over to the Lake Shore & Michigan Southern at Buffalo and hauled to Cleveland 183 miles distant at an average speed of 67 miles per hour, and a glance at the condensed profile of the latter Railway will show that the general contour is virtually on a descending grade for 67 per cent of the Division, therefore, the higher average speed is easily accounted for.

The tabulation of replies, as shown in the fore part of this paper, refers to figures to show the different general designs of these locomotives and their parts, and of these numbers 1, 2, 3, 11, 12 and 13 describe locomotives as used by the New York Central Lines. Numbers 4 to 10 inclusive describe locomotives as used by the Pennsylvania Lines. Number 14 illustrates an Atlantic type of the standard used by the Baltimore & Ohio Railroad Company, and numbers 15 and 16, the two types, High Pressure and Compound, of the 4-4-2 Class, used by the Chicago, Burlington et Quincy Railroad, the valves and bushings for the latter engines being described in Numbers 17 and 18. These drawings are grouped immediately following the tabled portion of the report and the Author will be glad to supply any information regarding same, or the text, that may not be clearly understood, providing it is within his power. The Author sincerely regrets that a combination of circumstances renders it impossible to give more time to a paper of this description, but is obliged to curtail further remarks as we are in receipt of advice from the General Secretary that the time limit is at hand and our paper must be immediately transmitted, therefore, the indulgence of the Congress is earnestly solicited.

Special attention is directed to the last two paragraphs immediately preceding the tabulated portion of this paper, which refers to the report furnished by Mr. J. W. Kendrick, second Vice-President of the Atchison Topeka & Santa Fe Railway Company appearing in the Appendix and in connection with the report embraces figures 22 to 31 inclusive, describing the locomotives used, the principal figures being numbers 22, 26, 27, 28 and 29, and we trust that no Member will fail to give this very complete report a thorough study.

APPENDIX.

Answers of the Atchison Topeka & Santa Fe Railroad to detailed list of questions relating to question VII.

QUESTIONS.	ANSWERS.
QUESTION I.	
Type and number of locomotives for high speed.	
Do you own or operate steam locomotives, which in regular service are required to transport trains at speeds of 50 miles per hour or more and if so :	
A. a) How many kinds of locomotives with detachable tenders?	One kind.
b) How many kinds of locomotives without detachable tenders?	None.
B. aa) How many locomotives, classified as to kind?	We have 121 locomotives of *Atlantic* balanced compound type. They all have the same diameter of cylinder and stroke and approximately the same weight on drivers, but differ slightly in some particulars, principally in the diameter of the drivers. The engine numbers and our own classification of the engines follow : Class 256 engines Nos. 256-260 ; diameter, drivers, 73 inches. — 507 — Nos. 507 541 ; — — 79 — — 542 — Nos. 542-559 ; — — 73 — — 1400 — Nos. 1400-1451 ; — — 79 — — 1550 — Nos. 1550-1561 ; — — 73 —
ab) How many locomotives, classified as to kind?	None.
QUESTION II.	
Principal features of permanent way governing operation and schedule speeds.	
I. On regularly operated divisions where speeds of 50 miles per hour or more are maintained, how great are respectively :	
A. Distances in miles.	
a) Mean rise in grade, in feet (in percentage), in 100 lineal feet?	See table I, column 1.
b) Greatest rise in grade, in feet (in percentage), in 100 lineal feet?	See table I, column 2.

QUESTIONS.	ANSWERS.
QUESTION II. (Continued.)	
c) Maximum grade, rise in feet (in percentage), in 100 feet?	See table I, column 3.
d) Maximum grade length, in miles?	See table I, column 4.
e) Mean fall in grade, in feet (in percentage), in 100 lineal feet?	See table I, column 5.
f) Greatest fall in grade, in feet (in percentage), in 100 lineal feet?	See table I, column 6.
g) Radius of the sharpest curve, in feet?	See table I, column 7.
II. How great are the regular scheduled speeds over the individual given in *A* (*a* to *g*).	
a) Mean speed required to maintain scheduled speed on divisions 50 miles or over in length?	See table I, column 8.
b) Greatest speed required to maintain scheduled speed on divisions 50 miles or over in length?	See table I, column 9.
QUESTION III.	
Consist of trains, used in regular traffic.	
I. What is the size of trains described in Question II, taking into consideration the designated distances, as well as the rate of speed, in regard to:	
A. Number of axles?	See table I, column 10.
B. Weight, in tons?	See table I, column 11.
II. What is the usual make-up of these trains so far as cars are concerned:	
A. In regard to number of axles (two, three, four or six-axled cars).	See table I, column 12.
B. In regard to the presence of entirely or partially enclosed (vestibuled) platforms between the various cars.	See table I, column 14.
C. In regard to the weight of the individual cars?	See table I, column 13.
QUESTION IV.	
Length of time since entering the service and the distance traversed by these locomotives.	
I. Since when have the locomotives named in your answer to Question I, been in regular service for the transportation of trains at speeds of 50 miles per hour or greater?	Class 256 engines, July, 1903. — 507 — May, 1904. — 542 — June, 1904. — 1400 — Aug., 1905. — 1550 — Aug., 1905.

QUESTIONS.	ANSWERS.
QUESTION IV. (Continued.)	
What are the greatest distances, in miles, traveled in this way by a locomotive?	
2. Without stops :	The greatest distances traveled without stops are : Between "time-carded stops", 112 miles; — "water-stops" . . 78·1 miles.
3. Without change of locomotive :	The greatest distance traveled without change of locomotive is 238·8 miles.
What is the average yearly service, in miles, given by locomotives running in through service hauling high speed trains (including in your calculation)?	55,200 miles.
1. The number of locomotives required to fill the runs?	See table I, column 15.
Also to protect the service?	See table I, column 16.
3. Also the number of locomotives required in the above service, in addition to those mentioned, but which are at the time undergoing repairs?	See table I, column 17
QUESTION V.	
incipales features of locomotives and tenders.	
Locomotives.	
1. Boiler :	
a) Heating surface of the fire-box (fire side)?	Class 256, 190 square feet. — 507, 190 — — — 542, 190 — — — 1400, 190 — — — 1550, 190 — —
b) Heating surface of the fire tubes (water side)?	Class 256, 2,893 square feet. — 507, 3,016 — — — 542, 3,016 — — — 1400, 3,016 — — — 1550, 3,016 — —
c) Heating surface of the superheater?	None.
d) Heating surface (total)?	Class 256, 3,083 square feet. — 507, 3,206 — — — 542, 3,206 — — — 1400, 3,206 — — — 1550, 3,206 — —

QUESTIONS.	ANSWERS.
QUESTION V. (Continued.)	
e) Working steam pressure (pounds per square inch)?	Class 256, 220 lb. per square inch. — 507, 220 — — — — 542, 220 — — — — 1400, 220 — — — — 1550, 220 — — —
f) Height of center line of boiler above top of rails?	256 class, 108 inches. 507 — 111 — 542 — 108 — 1400 — 111 — 1550 — 108 —
g) Length of fire tubes, between tube sheets?	256 class, 217 inches. 507 — 226 — 542 — 226 — 1400 — 226 — 1550 — 226 —
h) Outer diameter of fire tubes?	256 class, 2 1/4 inches. 507 — 2 1/4 — 542 — 2 1/4 — 1400 — 2 1/4 — 1500 — 2 1/4 —
Inner diameter of fire tubes?	The tubes are No. 11 B. & W. gauge and the th is therefore approximately 1/8 " of an inch inner diameter is therefore ". 256 class, 2 inches. 507 — 2 — 542 — 2 — 1400 — 2 — 1550 — 2 —
i) Outer : N° superheaters used.	No superheaters used.
Inner : diameter of superheater tubes, in inch?	
k) Length of grate in the clear?	256 class, 107 15/16 inches. 507 — 107 15/16 — 542 — 107 15/16 — 1400 — 107 15/16 — 1550 — 107 15/16 —
l) Width of grate in the clear?	256 class, 66 inches. 507 — 66 — 542 — 66 — 1400 — 66 — 1550 — 66 —
m) Grate area?	256 class, 49·5 squares inches. 507 — 49·5 — — 542 — 49·5 — — 1400 — 49·5 — — 1550 — 49·5 — —

QUESTIONS.	ANSWERS.
QUESTION V. (Continued).	
B. Cylinders :	
a) Number of high pressure cylinders?	Two.
b) Position of high pressure cylinders (inside or outside)?	The high pressure cylinders are inside of the frames.
c) Diameter of high pressure cylinders?	15 inches.
d) Stroke of high pressure cylinders?	26 inches.
e) Volume of high pressure cylinders (diameter times stroke)?	4,594·46 cubic inches, or 2·6588 cubic feet.
f) Number of low pressure cylinders?	Two.
g) Position of low pressure cylinders (inside or outside)?	The low pressure cylinders are outside of the frame.
h) Diameter of low pressure cylinders?	25 inches.
i) Stroke of low pressure cylinders?	26 inches.
k) Volume of low pressure cylinders (diameter times stroke)?	12,762·62 cubic inches or 7·3857 cubic feet.
l) Ratio of area of low pressure cylinder to area of high pressure cylinders?	Area of low pressure cylinders; area of high pressure cylinders : 490·87 square inches; 176·71 square inches or area of low pressure cylinders; area of high pressure cylinders : 2·777 : 1.
C. Factors governing general design :	
a) Ratio of total heating surface to grate area?	256 class, 62·288 : 1. 507 — 64·767 : 1. 542 — 64·767 : 1. 1400 — 64 767 : 1. 1550 — 64 767 : 1.
b) Ratio of theoretical tractive power to the adhesive weight?	See table II, items 6 and 7.
c) Coefficient used in determining the adhesive weight?	Coefficient used was 0·225.
d) Ratio of heating surface (in square feet) to the cylinder volume (in cubic feet)?	The corresponding cylinder for simple engine would be about 19 3/4 × 26; cylinder volume 4,589 cubic feet. Cylinder volume; total heating surface : 256 class, 1 : 671·8 507 — 1 : 698·4 542 — 1 : 698·4 1400 — 1 : 698·4 1550 — 1 : 698·4
D. Wheels :	
a) Number of driving wheels?	Four.

QUESTIONS.	ANSWERS.
QUESTION V. (Continued.)	
b) Outside diameter of driving wheels?	256 class, 73 inches. 507 — 79 — 542 — 73 — 1400 — 79 — 1550 — 73 —
c) Are all driving wheels fitted with flanged tires?	Yes.
d) Are all driving wheels connected by coupling rods?	Yes.
e) Number of leading wheels?	Four.
f) Outside diameter of leading wheels?	256 class, 34 1/4 inches. 507 — 34 1/4 — 542 — 34 1/4 — 1400 — 34 1/4 — 1550 — 34 1/4 —
g) Number of trailing wheels?	Two.
h) Outside diameter of trailing wheels?	256 class, 44 inches. 507 — 50 — 542 — 44 — 1400 — 50 — 1550 — 44 —
E. Axles :	
a) Total number of axles?	Five.
b) Number of axles used in pivoted trucks?	Two.
c) Number of axles used in rigid frames?	Three.
d) Number of driving axles?	Two.
F. Weights :	
a) Locomotive only (empty) tons?	See table II, column 10.
b) Locomotive only (in working order), tons?	See table II, column 11.
c) Locomotive only (on driving wheels), tons?	See table II, column 1.
d) Total tractive power (pounds)?	See table II, column 5.
e) Ratio of total tractive power (in pounds), to the total weight of locomotive on driving wheels (in pounds), to the total weight of locomotive on driving wheels (in pounds), when in working order?	See table II, columns 8 and 9.
II. Tenders :	
A. Number of axles?	Four.
B. Capacities :	
a) Water?	8,500 gallons.
b) Fuel?	12 tons.

QUESTIONS.	ANSWERS.
QUESTION V. (Continued.)	
C. Weights :	
a) Tender, when empty (tons)?	33·01 tons.
b) Tender, when in working order, with general equipment, fuel and water (tons)?	82·16 tons.
I. A drawing of the locomotive and tender about $^{1}/_{50}^{th}$ actual size, giving principal measurements designated in inches, also the various weights per axle (in tons) in desired?	A drawing of the locomotive and tender to the scale of $^{1}/_{2}$ inch = 1 foot and showing the principal dimensions and weights per axle is attached hereto.
QUESTION VI.	
Component parts of the locomotive.	
I. Superheater :	
A. What method of construction is used. (Sketches and explanations are requested)?	No. superheater is used.
I. Steam distribution :	
A. What kind of valves are used for distribution of steam to the cylinders?	Piston slide valves are used with solid or what is known as spring ring packing?
a) Flat slide valves?	
aa) Balanced?	
ab) Unbalanced?	
b) Piston slide valves?	
ba) With sectional ring packing, spring supported?	
bb) With solid or what is known as spring ring packing?	
C. What means are used to prevent loss of temperature in the steam supplied to the cylinders?	All insulation on the outside surfaces of the steam chests and cylinders is a paste composed of 85 per cent magnesium carbonate and 15 per cent long asbestos fibre. No. steam jacketing is used.
ca) Insulating covering on walls of steam chests or valve chambers?	
cb) Insulating covering on walls of cylinders?	
cc) Steam jacketing of walls of steam chest or valve chamber?	
cd) Steam jacketing of walls of cylinder?	
ce) Describe any other method that may be used.	
d) If relief valves are used, describe same.	Three kinds of relief valves are used- namely, cylinder relief valve as shown on print $^{33}/_{102}$, valve chamber relief valve shown on print $^{176}/_{13}$ and relief valve in T-head shown on print $^{36}/_{76}$.
e) If no relief valves are used, what appliances are used in their place?	

QUESTIONS.	ANSWERS.
QUESTION VI. (Continued).	
B. What type of valve motion or gearing is used on the high pressure cylinders?	Steam is supplied to both high and low pressure cyli ders on one side of the engine by one valve which actuated by Stephenson link motion.
C. What type of valve motion is used on the low pressure cylinders? Drawings of the valve motion and distributing valves are desired.	Drawing of this valve motion and sectional view of t cylinder and valve is shown on attached print No 1(
D. If you have any data based on actual service records in regard to the serviceability of the valve motions referred to in your answers to *B* and *C*, also similar data in regard to cost of maintenance of these parts, a copy of same is desired.	We have no special data regarding the cost of main nance of the valve gears of these engines. Howev their service has been generally satisfactory and t cost of maintenance is not excessive in comparis with the same kind of gears on engines not operat in high speed service.
III. Counterbalance :	
A. What percentage of the total weight of the reciprocating part is used in connection with the revolving weights in determining the proper counter-balance for the driving wheels?	Since these engines are of the balanced compound ty no empirical formula has been used in determini the proper weights for the counter-balances; on t other hand, the proper weights for the count balances have been determined by the customary a heoretical methods now in use.
B. Is the weight referred to in your answer to *A*, distributed in the counter-balance weight of, *a*) All coupled driving wheels, *b*) Or confined to the main wheel only, *c*) Or in what other way?	
IV. Flexibility :	
A. What is the rigid wheel base of the locomotive? (feet.)	256 class, 15 feet. 507 — 15 — 9 inches. 542 — 15 — 9 — 1 400 — 15 — 9 — 1 550 — 15 — 9 —
B. What lateral movement is provided between the wheel hubs and journal boxes of leading, driving and trailing wheels, also in swing motion trucks, giving the movement for each (in inches), measured from the centeral position?	$^1/_8$ lateral movement is provided between the wh hubs and the journal boxes of the leading, drivi and trailing wheels.
C. What is the radius (measured in feet) of the sharpest track curve over which the locomotive by reason of the flexibility provided for, can pass?	358 feet.

QUESTIONS.	ANSWERS.
QUESTION VI. (Continued.)	
Lubricating appliances :	
A. Do you use « Centrally located » lubricating appliances, for various groups of moveable parts of the locomotive?	We do not use centrally located lubricating appliances for the various groups of moveable parts. As a rule, each of these moveable parts is provided with its own oil or grease cup or cellar. The lubrication of the cylinder is, of course, provided for by the sight feed lubricator in the cab.
B. How is the flow of the lubricant regulated with reference to the working of the locomotive?	No automatic device is used to regulate the flow of the lubricant with reference to the working of the locomotive. The various lubricating appliances are controlled entirely by the engineer.
Brakes :	
A. Is it considered necessary to apply brakes to all or only a part of the wheels of a locomotive when used in high speed service?	It is deemed desirable to apply brakes to all the wheels of the locomotive, and this is done where it is possible to do so. However, some of the engines referred to in the answers to these questions have a construction of the truck which will not permit the use of truck brakes.
B. What is the percentage of braking power used, with reference to the total weight of the locomotive in working order? *a*) On the locomotive wheels? *b*) On the tender wheels?	On the driving wheels the braking power amounts to 75 per cent of the total weight; on the trailing wheels the braking power amounts to 65 per cent of the total weight; on the truck wheels the braking power amounts to 60 per cent of the total weight; on the tender wheels the braking power amounts to only 75 per cent of the light weight of the tender.
Miscellaneous :	
A. Do you use on locomotives any particular or special form of construction of running or driving gears to suit high speeds?	We do not use any particular or special form of constructions of running or driving gear to suit the high speeds.
B. Do you use on tenders any particular or special form of construction of running or driving gears to suit high speeds?	
QUESTION VII. *Fuel.*	
Do you use a superior quality of fuel for high speed service as compared with fuel used in ordinary service?	The same quality of fuel is used for engines in the high speed service that is used in engines in ordinary service.
What is the analysis and heat producing power (British Thermal Units per pound) of the fuel generally used for high speed service.	See table III.

QUESTIONS.	ANSWERS.
QUESTION VIII. *Trial results.* Have you any data with reference to the consumption of water, fuel and lubricants, secured from actual trials of locomotives used for train transportation at speeds of 50 miles per hour or over, and what are they with reference to each?	One of the engines referred to in answer to these tions, engine 535, was tested at the St. World's Fair locomotive testing plant in 190 results of this test may be found on pages 540 of « Locomotive Tests and Exhibits, Pe vania Railroad System, Louisiana Purchase E tion, 1904. » In addition, this railroad company has made roa on some of the engines of the balanced com type. Table IV attached hereto shows the sun of the results of some of these tets.

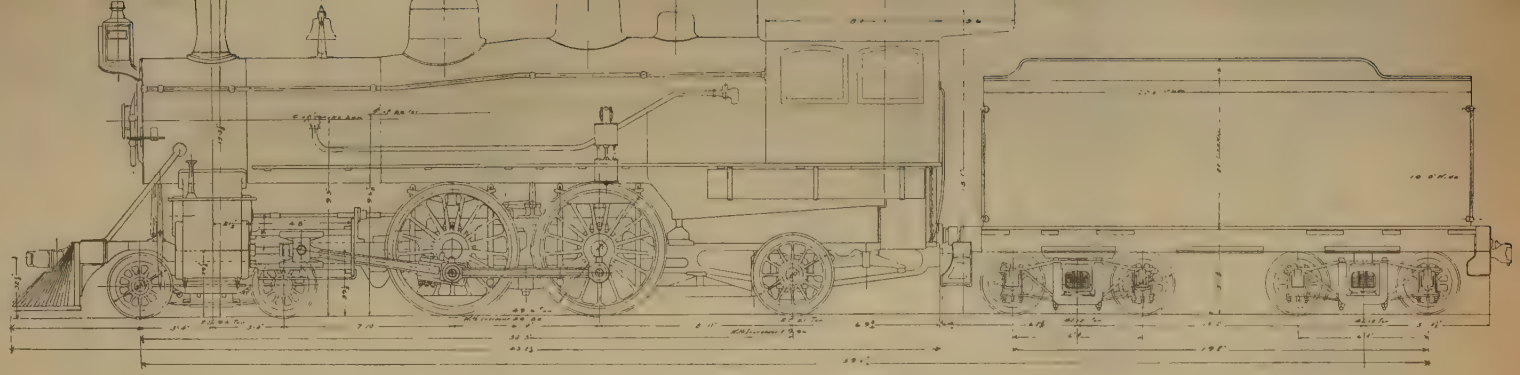


Fig. 22. — Atchison, Topeka & Santa Fe Railway. — Class 507. — Elevation.

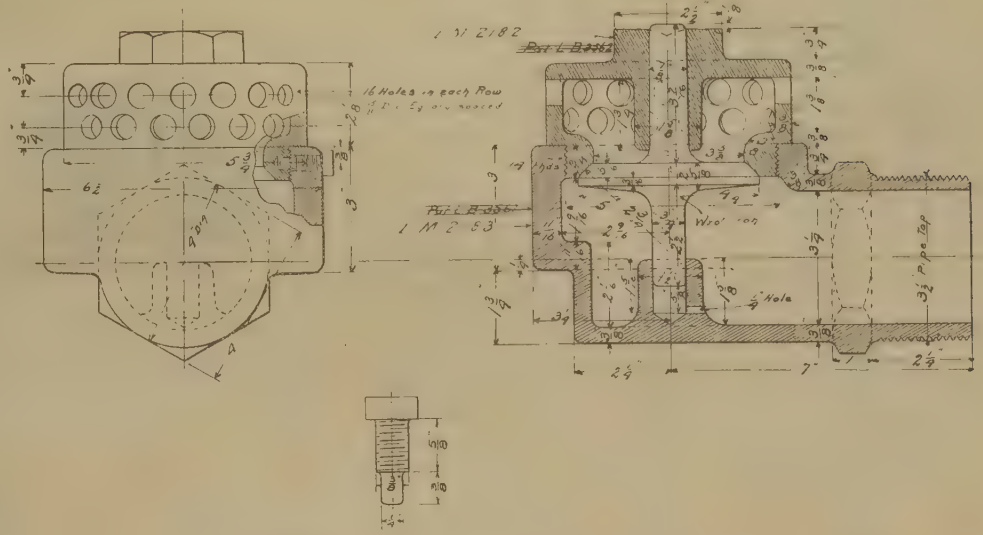


Fig. 23. — Atchison, Topeka & Santa Fe Railway. — Class 507. — Relief valve.

Note. — This valve screws into front valve chamber head of class 507.

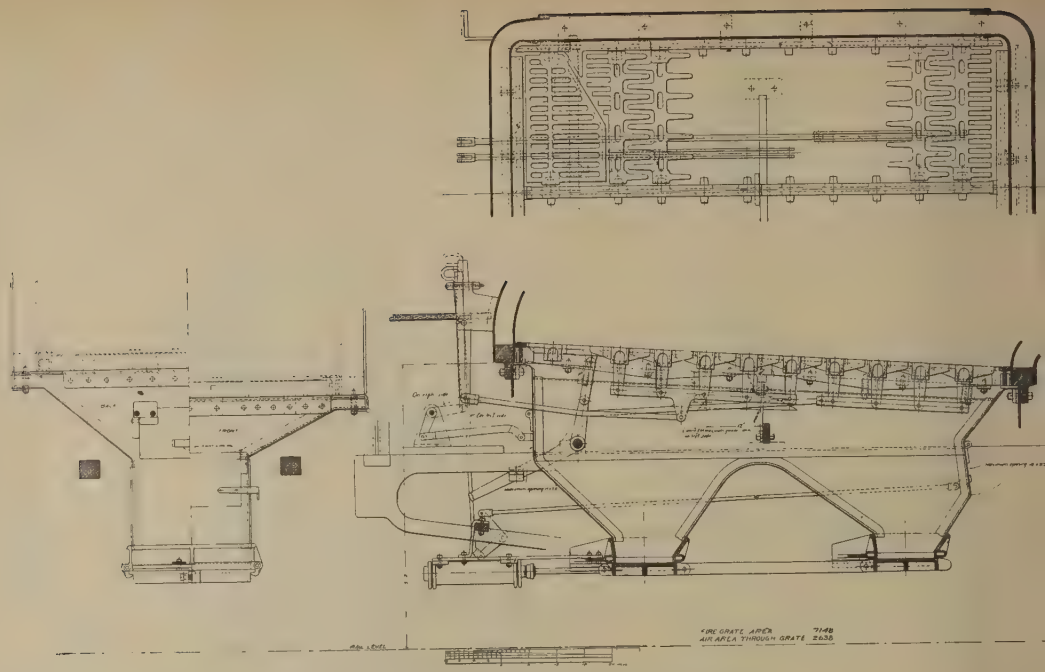


Fig. 24. — Atchison, Topeka & Santa Fe Railway.

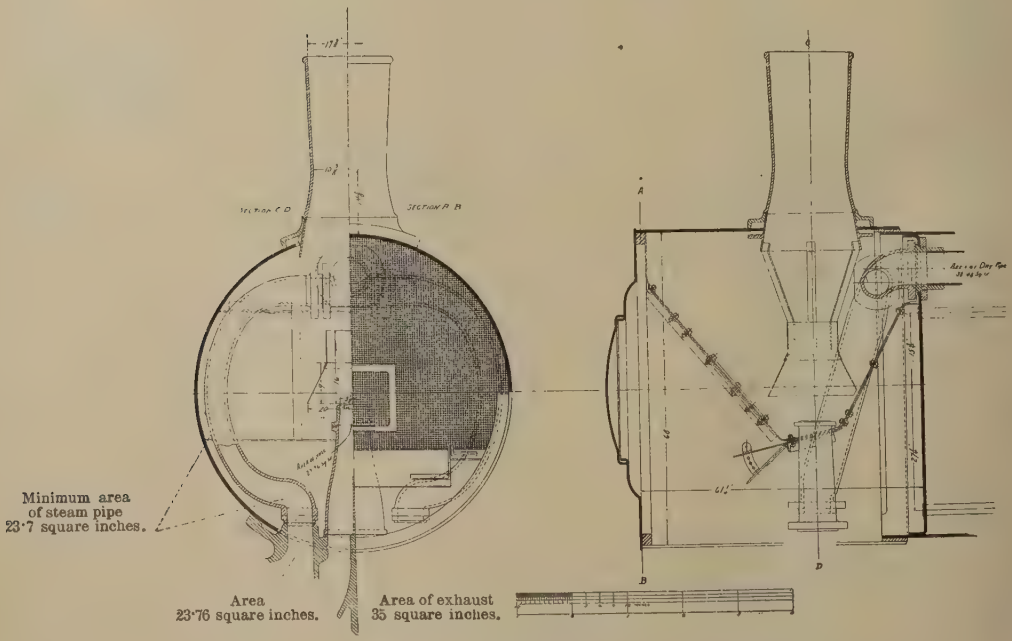


Fig. 25. — Atchison, Topeka & Santa Fe Railway.

Three nozzles furnished :

5 1/4	diameter	21·65 square inches area.
5 1/2	—	23·76 — —
5 3/4	—	26·97 — —

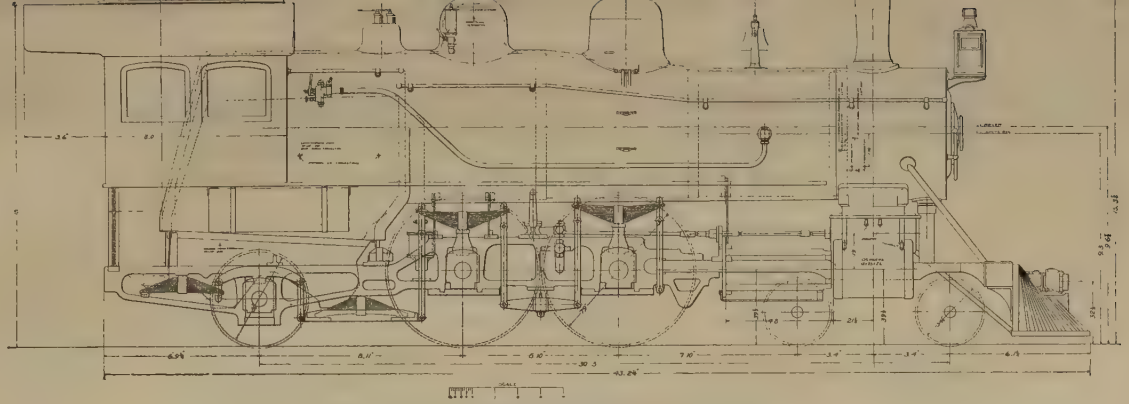


Fig. 26. — Atchison, Topeka & Santa Fe Railway.

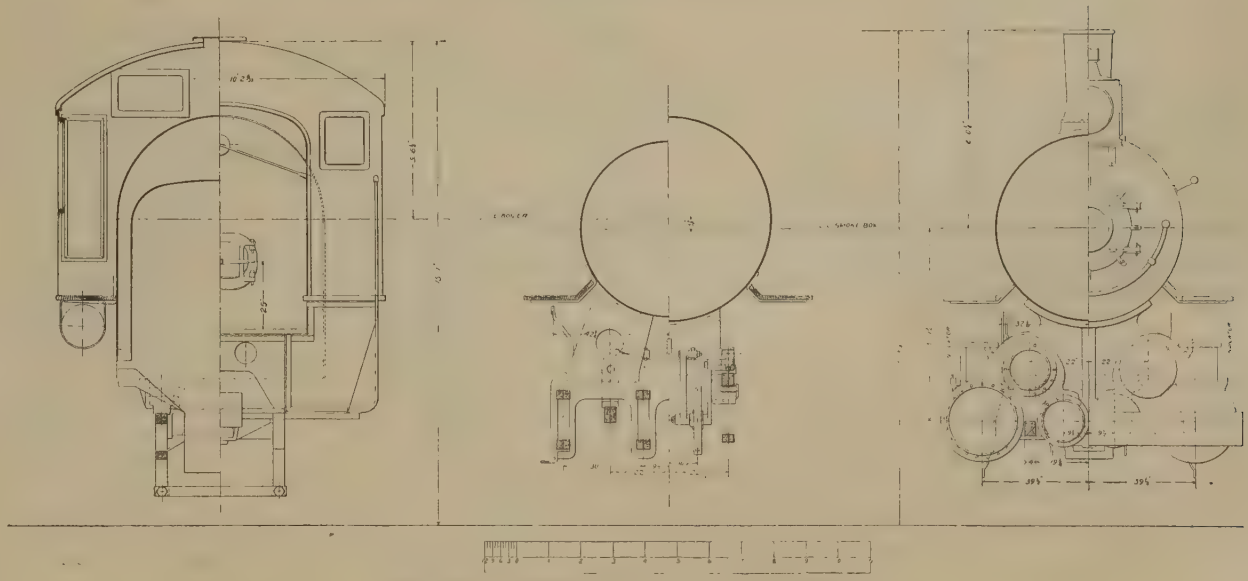
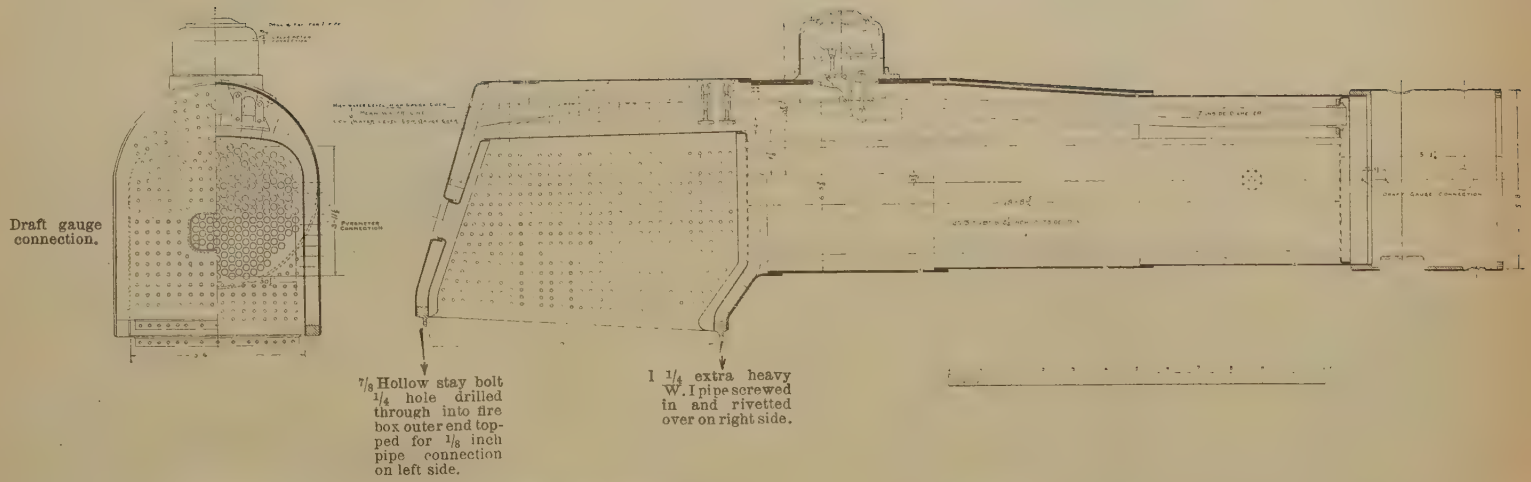


Fig. 27. — Atchison, Topeka & Santa Fe Railway.


Draft gauge connection.
7/8 Hollow stay bolt 1/4 hole drilled through into fire box outer end topped for 1/8 inch pipe connection on left side.
1 1/4 extra heavy W. I pipe screwed in and rivetted over on right side.

Fire area through tubes.

Grate area	49·5 square feet.		
External heating surface of tubes	2,304·0	—	—
Heating surface of fire box	190·0	—	—
Total heating surface	3,206·0	—	—
Boiler pressure	220 lb.		

Fig. 28. — Atchison, Topeka & Santa Fe Railway.

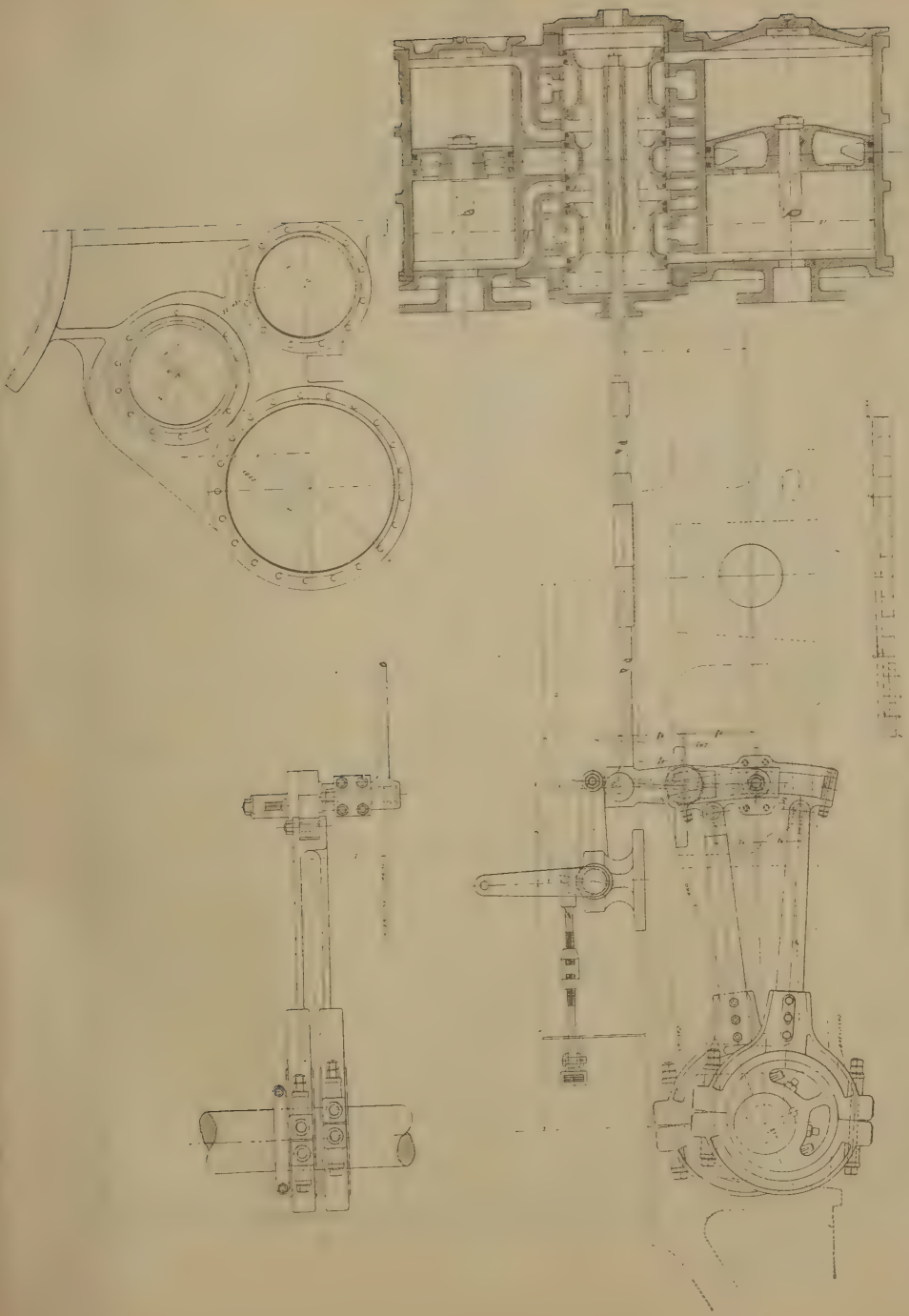


Fig. 29. — Atchison, Topeka & Santa Fe Railway.

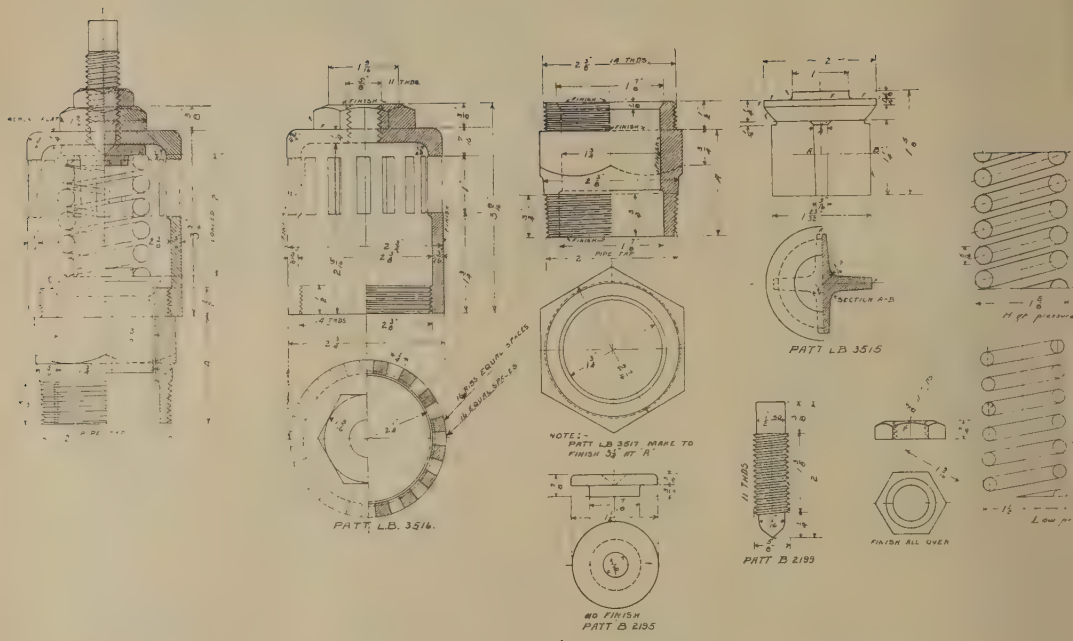


Fig. 30. — Atchison, Topeka & Santa Fe Railway. — Class 900. — Cylinder relief valve.

CLASS.	Length of A.				Blow off pressure.		*Remarks.*
	High Pressure.		Low Pressure.		High Pressure.	Low Pressure.	
	Front.	Back.	Front.	Back.			
256	...	...	2 1/4 inches.	3 1/4 inches.	...	140 lb.	
507	2 1/4 inches.	3 1/4 inches.	2 1/4 —	3 1/4 —	225 lb.	140 lb.	
542	2 1/4 —	3 1/4 —	2 1/4 —	3 1/4 —	225 lb.	140 lb.	
789	3 1/4 —	...	...	...	215 lb.	...	Tand. cylinder.
900	1 7/8 —	2 3/4 inches.	2 inches.	1 1/2 inches.	225 lb.	115 lb.	
1226	2 3/4 —	3 1/4 —	2 1/4 —	3 1/4 —	225 lb.	115 lb.	
1600	1 7/8 —	2 3/4 —	2 —	1 1/2 —	225 lb.	115 lb.	
1800	2 3/4 —	3 1/4 —	2 1/4	3 1/4 —	225 lb.	115 lb.	
1400	2 1/4 —	3 1/4 —	2 1/4 —	3 1/4 —	225 lb.	140 lb.	
1550							
1950	1 3/4 —	2 3/4 —	...	...	165 lb.	...	
1290	1 3/4 —	2 3/4 —	...	...	165 lb.	...	

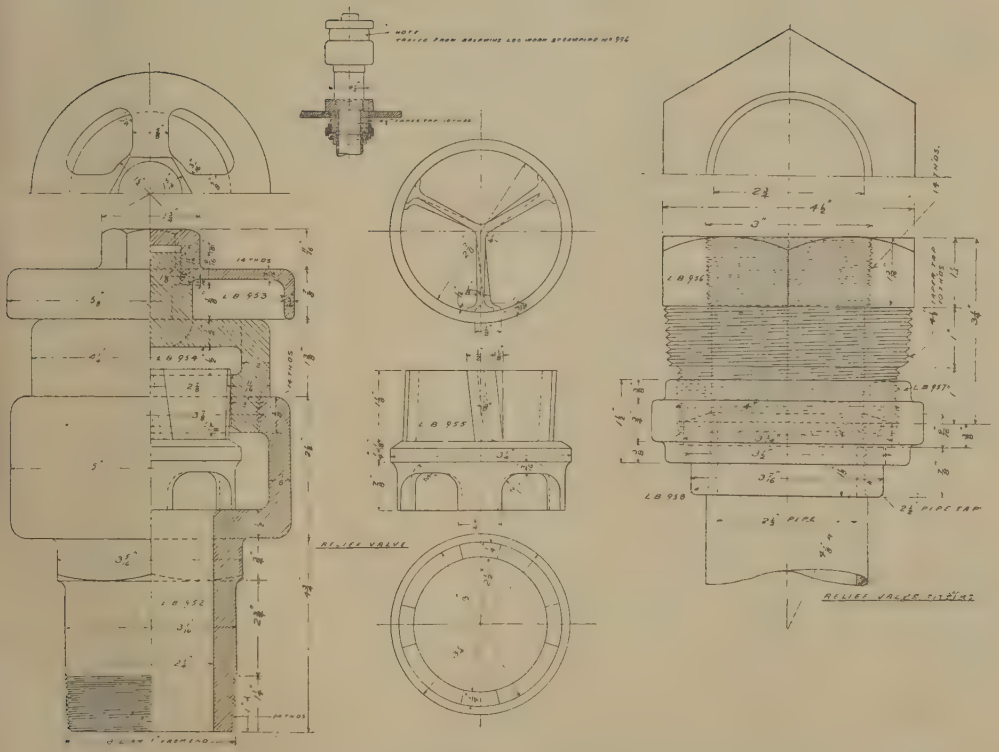


Fig. 31. — Atchison, Topeka & Santa Fe Railway. — Steam chest relief valve *Atlantic* type engines.

Table I.

Districts on which trains are scheduled 50 miles per hour or more.	Length division, in miles.	Grade rising.				Grade falling.		Radius sharpest curve, in feet.	Speed.	
		Mean.	Greatest (ruling).	Maximum.	Length maximum grade, in miles.	Mean.	Greatest (ruling).		Mean speed, in miles per hour.	Gr sp in h
		1	2	3	4	5	6	7	8	
Chicago, Ill., and Shopton, Ia.	...	...	...	...	...	...	...	...	...	
Westbound	238·8	0·211	0·600	1·10	5·09	0·206	0·600	573	...	
Train No. 1.	...	...	...	.	. .	. .	. .	...	36·8	
— No. 3.	...	...	...	...	.	.	.	...	...	
— No. 5.	...	...	...	...	. .	. .	.	...	34·0	
— No. 7.	.	...	...	...	.		...	...	42·4	
— No. 9.	...	...	...	...	...	...	...	...	42·4	
Eastbound	...	0·206	0·600	0·600	4·15	0·211	1·10	573	...	
Train No. 2.	...	...	...	. .	...	. .	...	...	...	
— No. 4.	...	...	...	...	...	. .	.	...	...	
— No. 6.	...	...	...	..	.	.	.	. .	35·6	
— No. 8.	...	...	...	...	. .		...	. .	...	
— No. 10.	...	...	...	...	.	...	...	...	...	
Shopton, Iowa, and Marceline, Mo.	112·6	...	...	...	...	...	...	...	...	
Westbound	...	0·498	0·800	0·800	3·55	0·894	0·800	894	...	
Train No. 1.	.	...	...	...	...	.	...	...	...	
— No. 3.	...	...	...	...	. .		. .	. .	...	
— No. 5.	..	. .	...	...	...	.	. .	...	...	
— No. 7.	..	. .	..	...	. .	. .	. .	...	41·2	
— No. 9.	...	...	...	...	...	...	...	...	...	
Eastbound	...	0·482	0·800	0·800	4·40	0·498	0·800	894	...	
Train No. 2.	...	...	...	...	. .	...	...	...	...	
— No. 4.	...	...	...	...	. .	.	. .	. .	...	
— No. 6.	..	. .	...	..	...		. .	.	...	
— No. 8.	...	. .	...	...	...	. .	...	. .	...	
— No. 10.	...	...	...	...	...	. .	...	...	...	

Note. — Under the heading *Districts on which trains are scheduled 50 miles per hour or more*, there is shown all trains which are filled out only for those trains whose scheduled speed reaches 50 miles hour ore more at any place in the district conssidered.

Table I.

Consist of trains (without locomotive) (and tender).										Number locomotives required to fill runs.	Number locomotives required to protect service.	Number locomotives in shops.
umber of cars.	Number of axles.	Train weight, in tons.	Number of car with				Weight tons individual cars.	Number of cars vestibuled.	Number of cars non-vestibuled.			
			Six-wheel trucks.		Four-wheel trucks.							
			Number cars.	Truck axles.	Number cars.	Truck axles.						
10	11	12	13				14	15		16	17	18
...	...	...	...	...	...	..	...	...	.	15	1	1
10	...	...	...	...	...	...	...	...	...	.	...	...
10	58	620	9	6	1	4	60-65	7	3		...	...
...	...	...	...	...	...	...	...	...	...	..	...	...
10	58	620	9	6	1	4	60-65	7	3		..	...
9	54	560	9	6	..	.	60-65	1	⸗	.	..	...
7	42	450	7	6		.	60-65	5	2	.	...	...
...	...	...	...	...			...	...	.		..	...
...	...	...	...	...	.		...	...			..	...
...	...	...	...	...	...	...	...	...	...	.	...	...
10	58	620	9	6	1	4	60-65	7	3		...	...
...	...	...		.	...	...	...	...	.		...	...
...	...	...	...	...	...	...	...	...	...	..	...	...
...	..	...	...	..	.	...	.	...	.	17	1	1
...	...	.						..		.	...	...
...	...	...	..	..	.			..		.	..	...
...	...	...	.		.		.	.	.		..	...
...	...	...	...	..	...	...	...	...	...	.	.	...
7	43	450	7	6	..	.	60-65	5	2	.	...	...
...	...	...	...			.	..	...	.	...	...	...
...	...	..	...	.		..			.	...	.	...
...	..	...	.	..		...	..	..	.	.	..	...
...	...	..	..	...	...	..		...		.	...	...
...	...	..	...	..	..			..			...	...
...	...	...	...	...	...	.	..	..	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...

the given district by the engines considered in the answers to the questions of the Congress; however, columns 8, 9, 10, 11, 12, 13 and 14 are

Table I. (Continued.)

Districts on which trains are scheduled 50 miles per hour or more.	Length division, in miles.	Grade rising.				Grade falling.		Radius sharpest curve, in feet.	Speed.	
		Mean.	Greatest (ruling).	Maximum.	Length maximum grade, in miles.	Mean.	Greatest (ruling).		Mean speed, in miles per hour.	Great spee in mi pe hou
		1	2	3	4	5	6	7	8	9
Marceline, Mo., and Kansas City, Mo.	...	...	...	...	...	...	...	...	...	...
Westbound	105·2	0·180	0·846	0·846	0·360	0·216	1·50	336	...	...
Train No. 1.	...	...	...	...	...	...	...	...	32·0	50·
— No. 3.	...	...	...	...	...	...	...	...	30·0	50·
— No. 5.	...	...	...	...	...	...	...	...	...	...
— No. 7.	...	...	...	...	...	...	...	...	35·6	50·
— No. 9.	...	...	...	...	...	...	...	...	33·7	50·
Eastbound	...	0·216	0·800	1·50	0·671	0·180	0·846	...	...	...
Train No. 2.	...	...	...	...	...	...	...	...	...	...
— No. 4.	...	..	...	...	...	...	...	...	32·8	50·
— No. 6.	...	...	...	...	...	...	...	...	...	...
— No. 8.	...	..	...	...	...	...	...	...	...	...
— No. 10.	...	...	...	...	...	...	...	...	...	...
Kansas City, Mo., and Topeka, Kans.	66·5	...	...	...	...	...	...	...	...	...
Westbound	...	0·143	0·500	0·567	0·113	0·119	0·660	598	...	...
Train No. 1.	...	...	...	...	...	...	...	...	...	...
— No. 3.	...	...	...	..	...	...	...	...	.	...
— No. 5.	...	...	..	...	...	...	...	...	...	...
— No. 9.	...	...	...	...	...	...	...	...	...	...
Eastbound	...	0·119	0·500	0·660	0·095	0·143	0·567	898	...	...
Train No. 2.	...	...	...	...	...	...	...	...	...	...
— No. 4.	...	..	..	...	...	..	...	...	36·3	53·
— No. 6.	.	..	..	...	...	..	...	...	34·6	53·
— No. 8.	...	...	..	...	...	...	...	...	...	...
— No. 10.	...	...	...	...	...	...	...	...	...	...

Table I. (Continued.)

Consist of trains (without locomotive) (and tender).										Number locomotives required to fill runs.	Number locomotives required to protect service.	Number locomotives, in shops.
mber of ars.	Number of axles.	Train weight, in tons.	Number of car with				Weight tons individual cars.	Number of cars vestibuled.	Number of cars non-vestibuled.			
			Six-wheel trucks.		Four-wheel trucks.							
			Number cars.	Truck axles.	Number cars.	Truck axles.						
10	11	12	13				14	15		16	17	18
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
10	58	620	9	6	1	4	60-65	7	3			
7	42	450	7	6	...	...	60 65	6	1			
...	...	...	...	...	...	...	...	...	...			
9	54	560	9	6	...	...	60-65	1	8			
7	42	450	7	6	...	...	60-65	5	2			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
7	42	450	7	6	...	...	60-65	6	1			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...	15	1	1
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			
7	42	450	7	6	...	...	60-65	6	1			
10	58	620	9	6	1	4	60-65	7	3			
...	...	...	...	...	...	...	...	...	...			
...	...	...	...	...	...	...	...	...	...			

Table I. (Continued.)

Districts one which trains are scheduled 50 miles per hour or more.	Length division, in miles.	Grade rising.				Grade falling.		Radius sharpest curve, in feet.	Speed.	
		Mean.	Greatest (ruling).	Maximum.	Length maximum grade, in miles.	Mean.	Greatest (ruling).		Mean speed, in miles per hour.	Great spee in mi pe hou
		1	2	3	4	5	6	7	8	9
Topeka, Kans. and Newton, Kans .	134·6	...	...	...	...	...	...	...	...	...
Westbound	...	0·303	1·15	1·15	0·322	0·325	1·00	866	...	...
Train No 1.	...	...	...	...	...	...	...	...	34·4	55
— No. 3.	...	...	...	...	...	...	...	...	38·4	55
— No. 5.	...	...	...	...	...	...	...	...	3)·4	55
— No. 9.	...	...	...	...	...	...	...	...	40·5	55
Eastbound . . .	...	0·325	1·00	1·00	0·455	0·303	1·15	866	...	...
Train No. 2.	...	...	...	...	...	...	...	...	33·0	50
— No. 4.	...	...	...	...	...	...	...	...	...	...
— No. 6.	...	...	...	...	...	...	...	...	...	...
— No. 8.	...	...	...	...	...	...	...	...	...	...
— No. 10.	...	...	...	...	...	...	...	...	...	...
Emporia, Kans., and Newton, Kans.	73·1	...	...	...	...	...	...	...	...	...
Westbound	...	0·303	1·15	1·15	0·322	0·325	1 00	866	...	...
Train No. 7	...	...	...	...	...	...	...	...	36·9	56
Newton, Kans., and Dodge, City, Kans.	107·4	...	...	...	...	...	...	...	...	...
Westbound	...	0·161	0·400	0·521	0·435	0·137	0·416	2,685	...	...
Train No. 1		...	...	...	...	...	...	...	33·1	50
— No. 3	...	...	...	...	...	...	...	...	...	...
— No. 5	...	...	...	...	...	...	...	...	...	...
— No. 7	...	...	...	...	...	...	...	...	...	...
— No. 9	...	...	...	...	...	...	...	...	...	...
Eastbound . . .	...	0·137	0·300	0·416	0·228	0·161	0·521	2,685	...	...
Train No. 2	...	...	...	...	...	...	...	...	...	...
— No. 4	...	...	...	...	...	...	...	...	...	...
— No. 6	...	...	...	...	...	...	...	...	...	...
— No. 8	...	...	...	...	...	...	...	...	...	...
— No. 10	...	...	...	...	...	...	...	...	...	...

Table I. (Continued.)

Consist of trains (without locomotive) (and tender).										Number locomotives required to fill runs.	Number locomotives required to protect service.	Number locomotives, in shops.
Number of cars.	Number of axles.	Train weight, in tons.	Number of car with.				Weight tons individual cars.	Number of cars vestibuled.	Number of cars non vestibuled.			
			Six-wheel trucks.		Four-wheel trucks.							
			Number cars.	Truck axles.	Number cars.	Truck axles.						
10	11	12	13				14	15		16	17	18
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
11	62	682	9	6	2	4	60-65	7	4	7	1	0
8	48	500	8	6	...	...	60-65	7	1	...	...	...
9	52	560	8	6	1	4	60-65	6	3	...	...	...
7	42	450	7	6	...	...	60-65	5	2	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
12	68	740	10	6	2	4	60-65	8	4	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	Included in assignments Marceline and Kans. City Kansas City and Topeka.		
...	...	...	...	...	...	...	...	...	...			
11	62	682	9	6	2	4	60-65	7	4			
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
9	52	560	8	6	1	4	60-65	7	2	11	1	0
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...

Table I. (Continued.)

Districts on which trains are scheduled 50 miles per hour or more.	Length division, in miles.	Grade rising.				Grade falling.		Radius sharpest curve, in feet.	Speed.	
		Mean.	Greatest (ruling).	Maximum.	Length maximum grade, in miles.	Mean.	Greatest (ruling).		Mean speed, in miles per hour.	Grea spee in m pe hou
		1	2	3	4	5	6	7	8	9
Dodge City, Kans., and La Junta, Colo	202·2	...	...	...	...	...	...	...	...	...
Westbound	...	0·195	0·400	0·780	0·171	0·124	0·400	1,790	...	...
Train No. 1	...	...	...	...	...	...	...	...	...	...
— No. 3	...	...	...	...	...	...	...	...	...	...
— No. 5	...	...	...	...	...	...	...	...	...	...
— No. 7	...	...	...	...	...	...	...	...	...	...
— No. 9	...	...	...	...	...	...	...	...	36·8	50
Eastbound	...	0·124	0·400	0·647	0·152	0·195	0·400	1,790	...	...
Train No. 2	...	...	...	...	...	...	...	...	...	...
— No. 4	...	...	...	...	...	...	...	...	41·2	50
— No. 6	...	...	...	...	...	...	...	...	40·6	52
— No. 8	...	...	...	...	...	...	...	...	...	...
— No. 10	...	...	...	...	...	...	...	...	34·8	50
Gallup, N. M. and Winslow, Ariz.	128·0	...	...	...	...	...	...	...	...	...
Westbound	...	...	0·333	0·333	1·11	0·240	0·333	573	...	...
Train No. 1	...	...	...	...	...	...	...	...	...	...
— No. 3	...	...	...	...	...	...	...	...	41·5	51
— No. 7	...	...	...	...	...	...	...	...	41·7	51
Eastbound	...	...	0·333	0·333	1·04	0·246	0·333	573	...	...
Train No. 2	...	...	...	...	...	...	...	...	...	...
— No. 4	...	...	...	...	...	...	...	...	...	...
— No. 8	...	...	...	...	...	...	...	...	...	...

Table I. (Continued.)

Consist of trains (without locomotive) (and tender).										Number locomotives required to fill runs.	Number locomotives required to protect service.	Number locomotives, in shops.
umber of cars.	Number of axles.	Train weight, in tons.	Number of car with				Weight tons individual cars.	Number of cars vestibuled.	Number of cars non-vestibuled.			
			Six-wheel trucks.		Four-wheel trucks.							
			Number cars.	Truck axles.	Number cars.	Truck axles.						
10	11	12	13				14	15		16	17	18
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	13	1	1
...	...	...	...	...	...	...	..	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
8	48	500	8	6	...	...	60-65	6	2	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
7	42	450	7	6	...	...	60-65	6	1	...	...	...
9	52	560	8	6	1	4	60-65	6	3	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
9	52	560	8	6	1	4	60-65	6	3	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
6	36	375	6	6	...	...	60-65	6	...	6	1	0
7	40	450	6	6	1	4	60-65	4	3	...	...	...
...	...	...	..	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...
...	...	...	⋮	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...

Table II.

	Engine numbers.				
	Engines 256-259.	Engines 507-541 1400-1407.	Engines 542-559 1550-1556.	Engines 1408-1451.	Engines 1557-1561.
1° Weight on drivers	101,420	99,200	99,200	113,700	113,700
2° Same with traction increasers applied	111,920	109,700	109,700	...	...
3° Adhesive weight	22,820	22,320	22,320	25,580	25,580
4° Same with traction increaser applied	25,180	24,680	24,680	...	...
5° Tractive effort	24,000	22,200	24,000	22,200	24,000
6° Ratio of tractive effort to adhesive weight	1 : 0·9508	1 : 1·005	1 : 0·9300	1 : 1·1522	1 : 1·0658
7° Ratio of tractive effort to adhesive weight with traction increaser applied	1 : 1·0491	1 : 1·1110	1 : 1·0250	...	...
8° Ratio of tractive effort to total weight on drivers	1 : 4·2253	1 : 4·4685	1 : 4·1334	1 : 5·1216	1 : 4·7375
9° Ratio of tractive effort to weight on drivers with traction increaser applied	1 : 4·6633	1 : 4·9414	1 : 4·5708	...	...
10 Total weight of locomotive light, in tons	83·38	87·25	87·25	87·25	87·25
11° Total weight of locomotive in working order, in tons	96·88	100·75	100·75	100·75	100·75

Table III.

Analyses of coals used on the Atchison, Topeka & Sante-Fe Railroad (1907).

MINE AND SHAFT.	Proximate.					Ultimate.			British thermal units.
	Water.	Volatile	Fixed carbon.	Ash.	Total.	Hydrogen.	Carbon.	Sulphur.	
Big Four Mining, Coal City, III	14·88	35·21	45·00	4·91	100·00	...	...	2·25	11,110
Acme Mining Co., Streator, III.	9·70	38·33	45·86	6·11	100·00	...	...	2·81	11,988
Toluca Devlin Estate, No. 1.	11·22	36·80	45·90	6·08	100·00	5·03	66·13	2·59	12,154
Toluca Devlin Estate, No. 2.	10·51	36·89	45·46	7.14	100·00	...	...	3 33	11,865
Roanoke	12·33	36·13	44·58	6·96	100·00	4.69	63·52	3·39	11,801
Central Coal and Coke Co., Richmond, Mo.	13·89	33·66	42·59	9·86	100·00	4·67	58·85	4·05	10,406
Marceline, Mo., No. 1.	12·08	38·77	41·80	7·35	100·00	4·89	62·93	4·44	11,433
Marceline, Mo., No. 2.	11·99	37·59	41·88	8·54	100·00	...	...	4·18	11,010
Cherokee & Pittsburgh, No. 5	5·20	35·34	53·77	5·69	100·00	5·01	74·23	2·48	13,212
Cherokee & Pittsburgh, No. 6	3·52	35·31	49·44	11 73	100·00	5·00	68·26	5·75	12,825
Cherokee & Pittsburgh, No. 8	4·68	35·13	52·51	7·68	100·00	...	...	4·01	12,829
Cherokee & Pittsburgh, No. 9	3·25	37·26	50·74	8·75	100·00	...	...	4·76	12,690
Wear Coal Co., No. 17	3·54	36·81	53 47	6·18	100·00	...	...	3·88	13,022
Devlin Miller Co	3·55	37·18	51·65	7·62	100·00	...	...	4·35	13,487
Central Coal & Coke Co., No. 17	2·20	36·18	55·75	5·87	100·00	...	...	2·34	13,361
Central Coal & Coke Co., No. 31	1·73	33·10	49·92	15·25	100·00	...	...	3·89	12,664
Pittsburgh & Midway, No. 5	1·50	34·25	52·78	11·47	100·00	...	...	4·59	12,354
St. L. R. M. & P. Co., Van Houten Mine	1·61	36·84	52·58	8·97	100·00	...	...	0·79	13,098
St. L. R. M. & Co., Brilliant Mine.	1·60	37·25	50·83	10·32	100·00	...	...	0·78	12,741
C. F. & I. Co., Starkville.	1·57	31·67	54·22	12·54	100·00	5·11	73·53	0·69	12,779
C. F. & I. Co., Katcina at Morley	1·35	32·66	54·73	11·26	100·00	...	...	0·83	12,986
Victor Fuel Co., Delagua C. & S. E. Ry.	2·07	36·51	52 87	8·55	100·00	...	...	0·57	12,532
Victor Fuel Co., Hastings	1·70	35·04	53·20	10·06	100·00	5·16	75·41	0·67	13,113
Weaver near Gallup	12·19	38·29	43·75	5·77	100·00	...	...	0 76	11,214
Heaton near Gallup	9·71	41·85	42·92	5·52	100·00	4·76	65·10	0·90	11,722
Otero near Gallup	8·41	40·05	40·78	10·76	100·00	...	...	0·91	11,119
Clark 1 and 2 near Gallup	11·04	40 23	40·93	7·80	100·00	4·66	62·91	0.49	11,198
Weaver Mixed, Pea 60 per cent & Slack 40 per cent.	9·98	39·40	41·52	9·10	100·00	...	...	0 69	11,036
Weaver Slack	10·35	36·98	38·52	14·15	100·00	...	...	1·61	10,251
Weaver Pea.	10·03	37·87	41·35	10·75	100·00	...	...	0·50	10,959

ROAD TEST OF ENGINE No. 558.

Topeka, Kans., to Newton, Kans.

TRAINS No. 5 AND No. 6. (August 7-20, 1906.)

Tests made with I. C. S. Dynamometer car « Scranton ».

Test number.	Date.	Cars in train.	Tons in train.	Average speed miles per hour for trip.	Average speed miles per hour actual regular time.	Average lb. D. B. P. whole trip.	Average lb. D. B. P. while using steam.	Minutes engines was using steam.	Average lb. Boiler pressure.	Total lb. coal fired.	Total lb. water evaporate.	Lb. water evaporate per pound coal.	Lb. coal per D. H. P. hour.	Lb. coal per 1,000 ton-miles.	Lb. coal per train-miles.	Lb. coal per car-mile.	Lb. coal per minute engines used steam.	Injector on		Pops open		Blowers on		Number times grates shaken.
																		per cent of total time.	number times shut off.	per cent of total time.	number of times.	per cent of total times.	number of times.	
1	7	10	567	29·25	36·51	5,760	6,088	198·0	214	11,240	73,200	6·512	5·48	144·0	83·45	8·34	56·77	82·8	16	0·80	2	16·0	17	7
3	9	11	578	35·90	37·50	5,772	6,068	201·5	212	11,000	71,200	6·473	5·47	141·0	81·72	7·43	54·59	85·8	19	2·00	7	No record.		6
5	11	13	672	35 97	37·82	6,353	7,455	186·8	208	13,800	77,606	5·624	5·89	152·0	102·5	7·88	73·86	80 6	28	2·19	5	12·5	11	8
7	13	11	570	34 45	37·56	5,784	5,914	196·2	211	10,400	76,400	7·346	5·37	136·0	77·26	7·02	53·01	72·5	25	3·74	7	10·9	17	7
9	15	9	503	37·33	41·00	4,433	5,499	171·5	214	9,600	70,600	7·354	5·58	142·0	71·32	7·92	56·00	81·4	15	6·20	17	1·4	6	9
11	17	12	629	35·50	39·78	7,182	8,130	144·8	197	9,547	No record.		4·63	142·0	87·66	7·39	65·93	87·1	11	0·30	3	No record.		7
13	19	13	647	31 50	34·23	6,518	7,538	206·8	192	13,600	78,000	6·735	5·75	155·0	101·0	7·77	65·76	83·8	13	2·14	5	No record.		13
Newton, Kans., to Topeka, Kans.																								
2	8	12	629	34·58	38·92	4,823	4,883	189·0	210·3	9,750	58,400	5·99	6·25	115·1	72·44	6·04	51·5	85·7	16	2·4	5	2·7	1	16
4	10	10	544	35·42	40·04	4,503	4,717	187·0	209·0	9,400	60,400	6·42	6·30	131·9	69·84	6·98	50·26	61·0	28	8·4	8	2·1	5	2
6	12	14	705	37·14	38·80	6,163	6,281	192·9	203·5	10,400	66,600	6·42	4·90	100·9	77·26	5·52	53·83	73·4	22	1·1	5	6·1	9	5
8	14	14	726	32·40	36·98	6,755	7,229	196·7	210·9	10,000	72,200	7·12	9·40	102·3	74·29	5·31	50·76	76·6	20	7·9	19	11·6	20	9
10	16	10	498	39·18	42·78	4,338	4,535	173·7	199·0	9,075	64,400	7·56	6·12	133·4	67·42	6·74	53·03	73·8	21	0·5	6	1·3	20	6
12	18	10	608	35·82	41·46	3,520	4,764	140·7	215·0	9,800	67,250	6·86	7·93	119·8	72·81	6·62	69 65	72·6	15	15.2	18	No record.		7
(1) 14	20	16	799	30·56	37·62	4,889	5,582	71·6	206·0	5,902	32,400	5·49	8·83	135·0	108·30	6·77	65·48	79·1	8	6·8	6	No record.		0

(1) This run 54·5 miles long.

[621 .131.2]

REPORT N° 2

(all countries except America)

By Mr. COURTIN,

MEMBER OF THE BOARD OF WORKS,

MEMBER OF THE GENERAL ADMINISTRATIGN OF THE BADEN STATE RAILWAY.

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*

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A. — Retrospect on the previous consideration of this subject by the international railway Congress.

The question of the design of locomotives for fast trains has already been considered several times by the International Railway Congress. Thus at the London Session, in 1895, it appeared as question VI, " Express locomotives "; at the next session, at Paris in 1900, it appeared as question XII with the very similar title " Locomotives for trains run at very high speed ". At the last session, at Washington in 1905, the subject was again discussed, but not limited as before to fast locomotives only; for question V was entitled " Locomotives of great power ". Although this definition includes great tractive effort rather than high speeds, yet the reports submitted also gave particulars of a number of notable express locomotives.

As we see, the question of high speeds and of the most suitable means for attaining them has a certain vogue, not only with the travelling public, whose wishes, hopes and expectations in this respect are sometimes ahead of existing possibilities, but also with the railwaymen of the whole world, although, or perhaps because, they are acquainted with the difficulties which any satisfactory solution of the problem would have to overcome, and because these difficulties always act as a stimulus, to try to overcome them.

That the subject, in spite of its excellent and exhaustive treatment by the former reporters, is now once again considered, has its justification in the fact, that when the Congress meets for its eighth Session at Berne, ten years will have elapsed since it considered more particularly the question of high speeds and of locomotives suitable for attaining them. Now although such an interval of time may appear short, as regards many branches of human activity, yet it is considerable as compared with the age of railways and the present state of the development of the question. Ten years ago regulation speeds of 90 kilometres (56 miles) per hour were to be found on comparatively-few railways, and speeds higher than this were exceedingly rare; but now such speeds are usual on many railways and the means for attaining them are well known. Taking this into consideration, and also the thorough treatment the question of high speeds has received, as already stated, by the most competent experts, it appears advisable to limit the scope of the question by only considering locomotives hauling trains with regulation speeds exceeding 100 kilometres (62 miles) per hour.

B. — Results of the enquiry.

I. — Classification of the answers received.

The answers received to the list of questions relating to subject VI, show that speeds of 100 kilometres (62 miles) per hour and even more occupy much the same position at present in the countries to which this report applies (all countries affiliated to the International Railway Congress, except America) that the speed of 90 kilometres (56 miles) per hour did when this question was last considered at Paris in 1900.

Group 1. — The first group consists of forty railway administrations in the different parts of the world (America excluded). Most of these railways merely state that they have no trains having regulation speeds of 100 kilometres (62 miles) per hour; on a few of them the speed of 100 kilometres (62 miles) per hour is expressly specified as the maximum speed which must not be exceeded. A list of the railways belonging to this group is given in appendix I.

Group 2. — The second group consists of five railways. These state that they have, it is true, locomotives which can reach speeds of over 100 kilometres (62 miles) per hour, but that there are no trains having such regulation speeds, and that these speeds are not attained even exceptionally. This group includes the following railways :

1° *Denmark.* — Danish State Railway.
2° *Germany.* — Bavarian State Railway.
3° *Italy.* — Italian State Railway.
4° *Sweden.* — Swedish State Railway.
5° *Hungary.* — Hungarian State Railway.

Group 3. — The third group includes the railways which state that they have locomotives which can reach speeds of over 100 kilometres (62 miles) per hour, but that such speeds are attained either only exceptionally, or to make up lost time; but that no such speeds exist as regulation speeds in the time-tables.

This group includes the following six railways :

1° *Belgium.* — Belgian State Railway.
2° *Baden* — Baden State Railway.
3° *France.* — *a*) Paris-Lyons-Mediterranean Railway; *b*) French State Railway; *c*) Midi Railway.
4° *Great Britain.* — Great Central Railway.

Group 4. — Finally there is group 4, which includes those railway on which regulation speeds of over 100 kilometres (62 miles) per hour are attained every day in the regular service.

This group, which fully meets the question set includes ten railways, which are exclusively in France and Great Britain, as follows :

1° *France.* — *a*) French Eastern Railway; *b*) French Northern Railway; *c*) Orleans Railway.
2° *Great Britain.* — *a*) Caledonian Rail-

way; *b*) Great Eastern Railway; *c*) Great Western Railway; *d*) Lancashire and Yorkshire Railway; *e*) Midland Railway; *f*) North Eastern Railway; *g*) South Eastern and Chatham Railway.

II. — Number and design of locomotives reported.

As regards group 2, and perhaps also group 3, it is hardly necessary to draw special attention to the fact that it is probable that there are other railway administrations, particularly in Europe, who are under similar conditions. Such railways have probably not sent answers, because they considered the strict wording of the first question : " Do you own steam locomotives which in regular working haul trains at speeds exceeding 100 kilometres (62 miles) per hour? "; and as they would have to answer this question in the negative they probably did not consider themselves competent to give further information in connection with the subject of this report.

Strictly speaking, it would therefore be logical also to exclude the material supplied by the railways of groups 2 and 3, as they also were not in a position to answer the above first question in the affirmative, but this would be very inadvisable, as the answers kindly supplied by these administrations contain much valuable and welcome information. It is therefore included in this report.

The types of the locomotives are designated by the symbols adopted by the German *Verein*. The carrying axles or sets of carrying axles are designated by Arabic numerals, the driving axles or sets of them by Roman capitals, the front of the locomotive being always assumed to be directed towards the left.

The following instances are given, together with the designations used for locomotives in other countries, by way of comparison.

Front		2 A 1 (4-2-2, *Single driver*).
—		1 B (2-4-0).
—		2 B (4-4-0, *American*).
—		2 B 1 (4-4-2, *Atlantic*).
—		1 C 1 (2-6-2, *Prairie*).
—		2 C (4-6-0, *Ten-wheel*).
—		2 C 1 (4-6-2, *Pacific*), etc.

a) Locomotives of group 2

The chief dimensions and particulars of the locomotives included under this head are given in 2. Some further particulars are given below.

α) Denmark.

The Danish State Railway owns sixteen 2 B 1 four-cylinder compound locomotives with four-axled tenders; their design is shown in figures 1 to 5 (locomotives) and in figures 6 to 9 (tenders). A photograph of such a locomotive is reproduced in figure 10.

The cylinders are placed next to each other; the inside high-pressure cylinders act on the first driving axle, and the out-

Fig. 1.

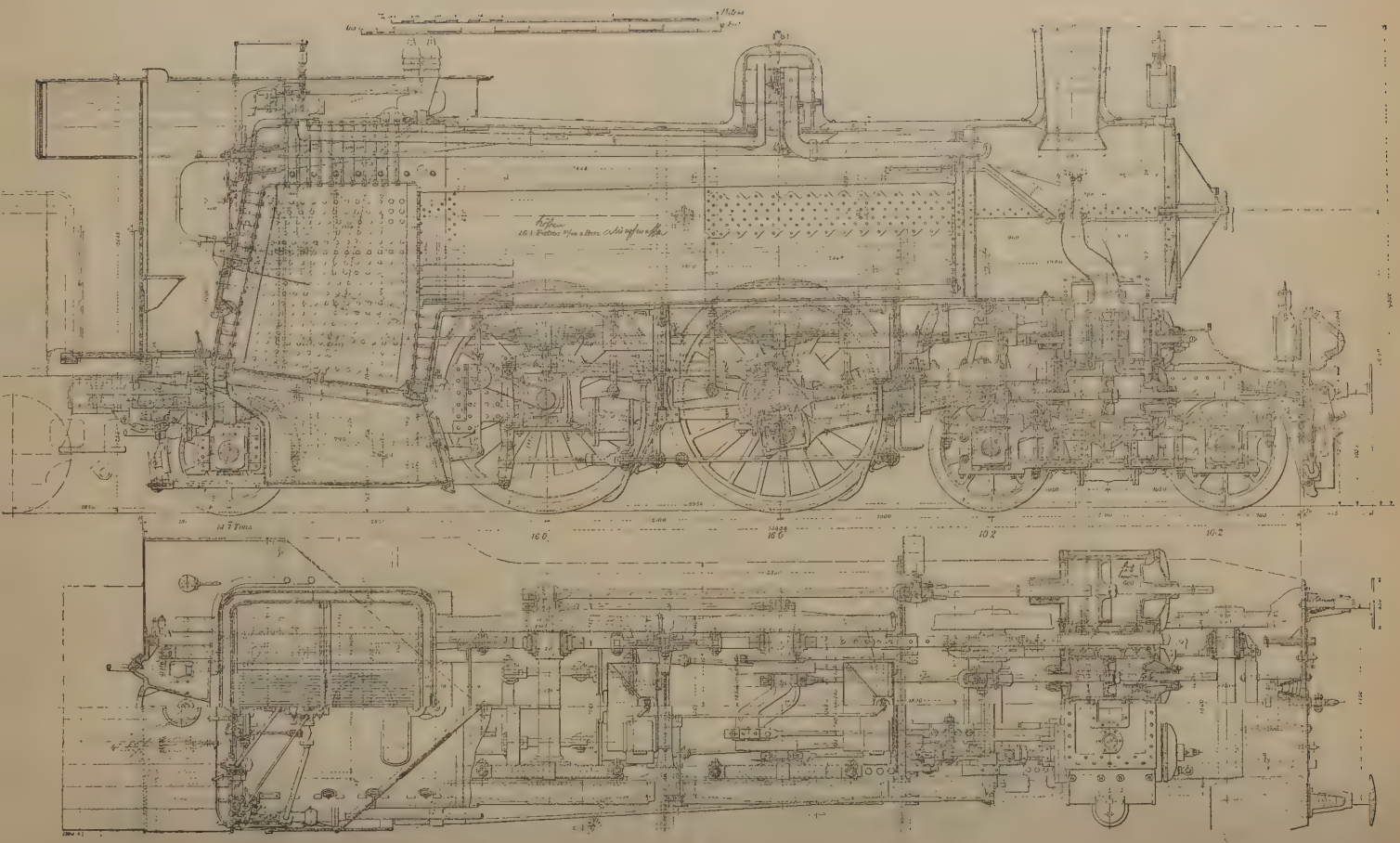


Fig. 2.

Figs. 1 and 2. — Group 2, α. — 2 B 1 Locomotive of the Danish State Railway.

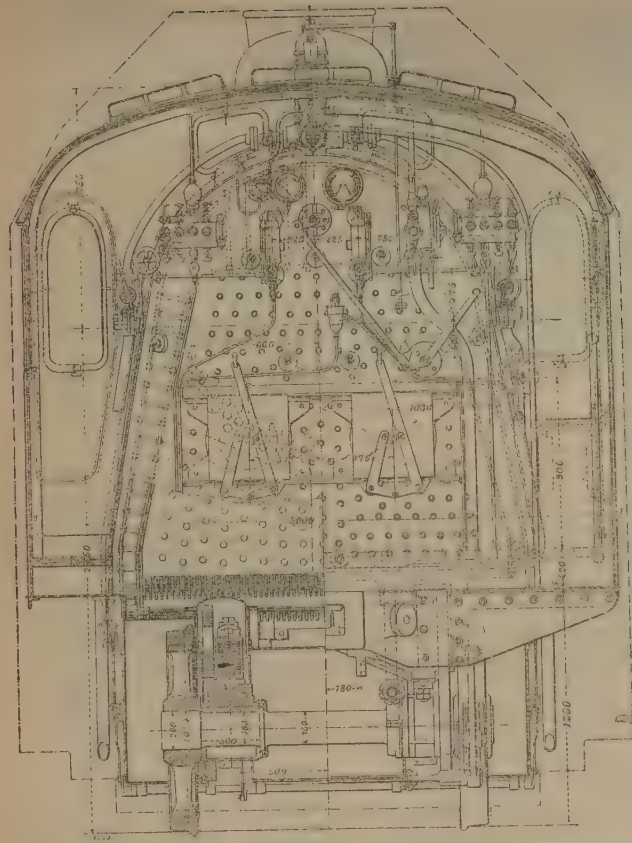


Fig. 3.

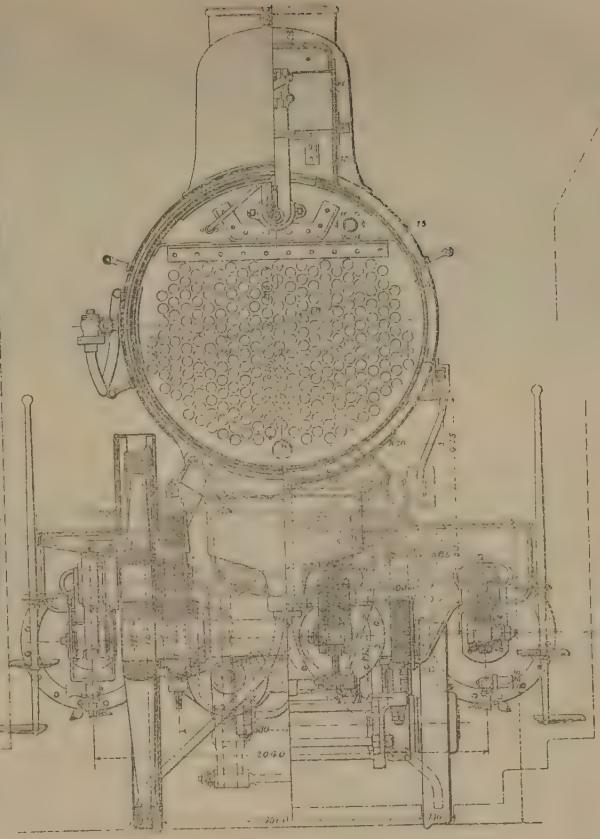


Fig. 4.

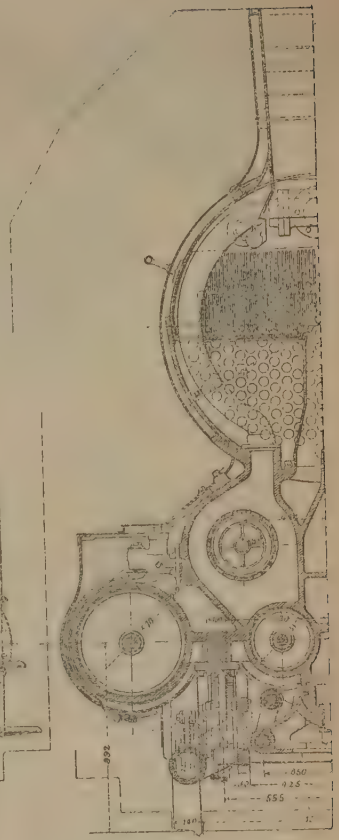


Fig. 5.

Figs. 3 to 5. — Group 2, α. — 2 B 1 Locomotive of the Danish State Railway.

Fig. 6.

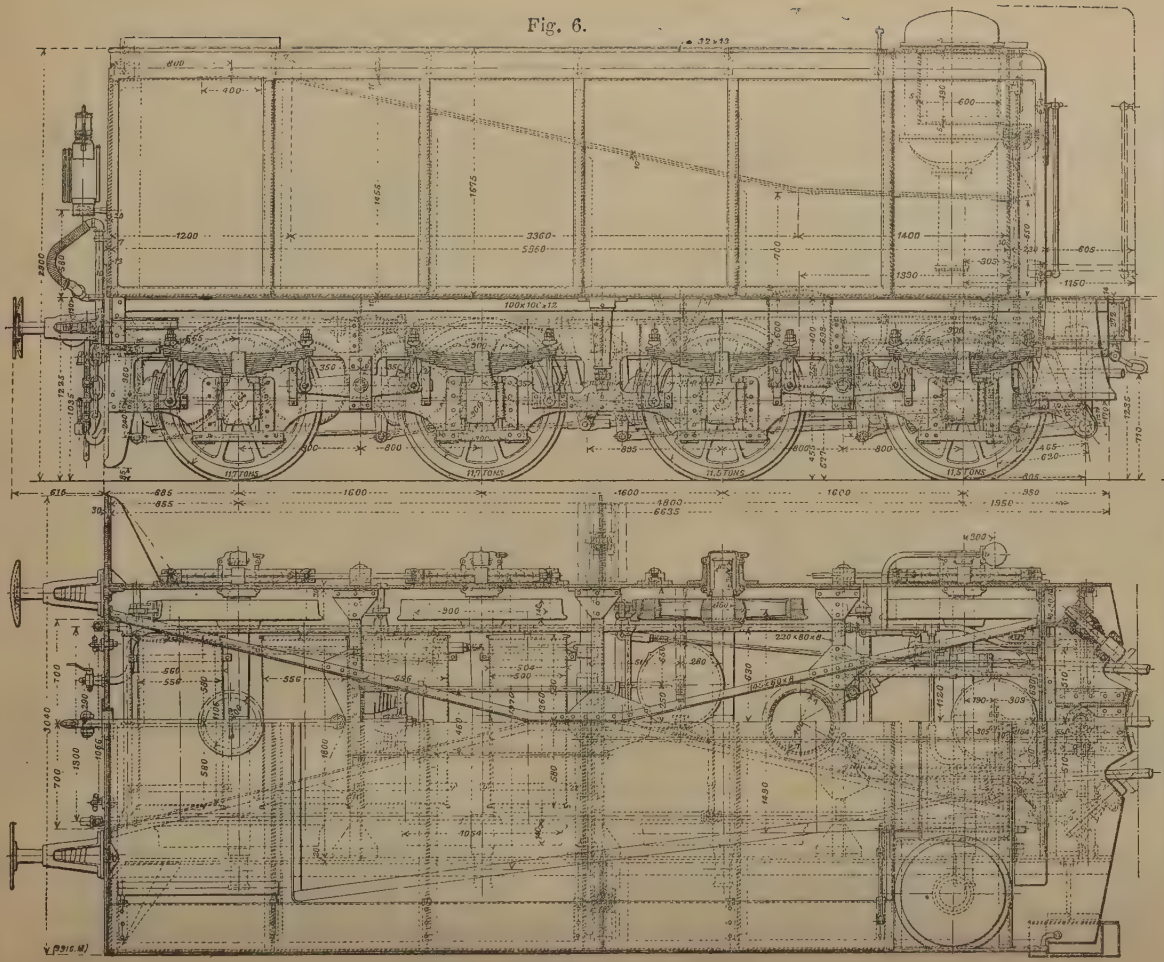


Fig. 7.

Fig. 8.

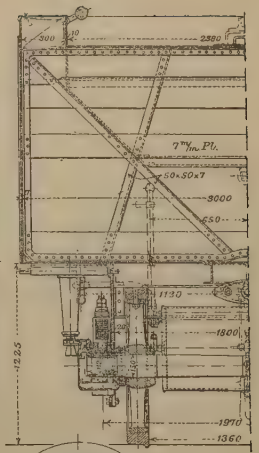


Fig. 9.

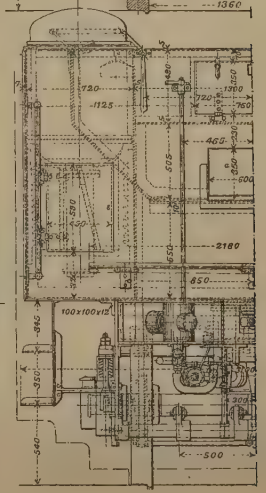


Fig. 10. — Group 2, 2. — 2 B 1 Locomotive of the Danish State Railway.

side low-pressure cylinders act on the second driving axle, the object aimed at being favourable conditions as regards the wear of the wheel tires.

All the four cylinders have piston valves. The front part of the frame is a bar frame, but becomes a plate frame in front of the fire-box. The wide grate extends beyond the frame and the trailing wheels, and so does the ash pan. The barrel consists of two rings, with serrated butt straps and treble riveting. The blast pipe is not adjustable.

The tender has four axles which are in one common frame; the first and the third have lateral play.

All the locomotive and tender axles are braked.

β) **Germany.**

The Bavarian State Railway states that it owns altogether ninety-two locomotives, which are capable of running at speeds exceeding 100 kilometres (62 miles) per hour. They are of four types, namely :

1° Ten of type 2 B 1 (fig. 11);
2° One of type 2 B 2 (fig. 12);
3° Sixty-five of type 2 C (fig. 13);
4° Sixteen of type 2 C 1 (fig. 14).

All of these locomotives are four-cylinder compounds and have piston valves; all have inside high-pressure and outside low-pressure cylinders The 2 B 2, the 2 C 1 and part of the 2 C locomotives are equipped with Schmidt smoke-tube superheaters.

In order to obtain a large grate area, the fire-box of the 2 B 1 and the 2 C locomotives is placed on the frame between the wheels; in the case of the 2 B 2 and the 2 C 1 locomotives, it extends beyond the plane of the wheels, for the same reason.

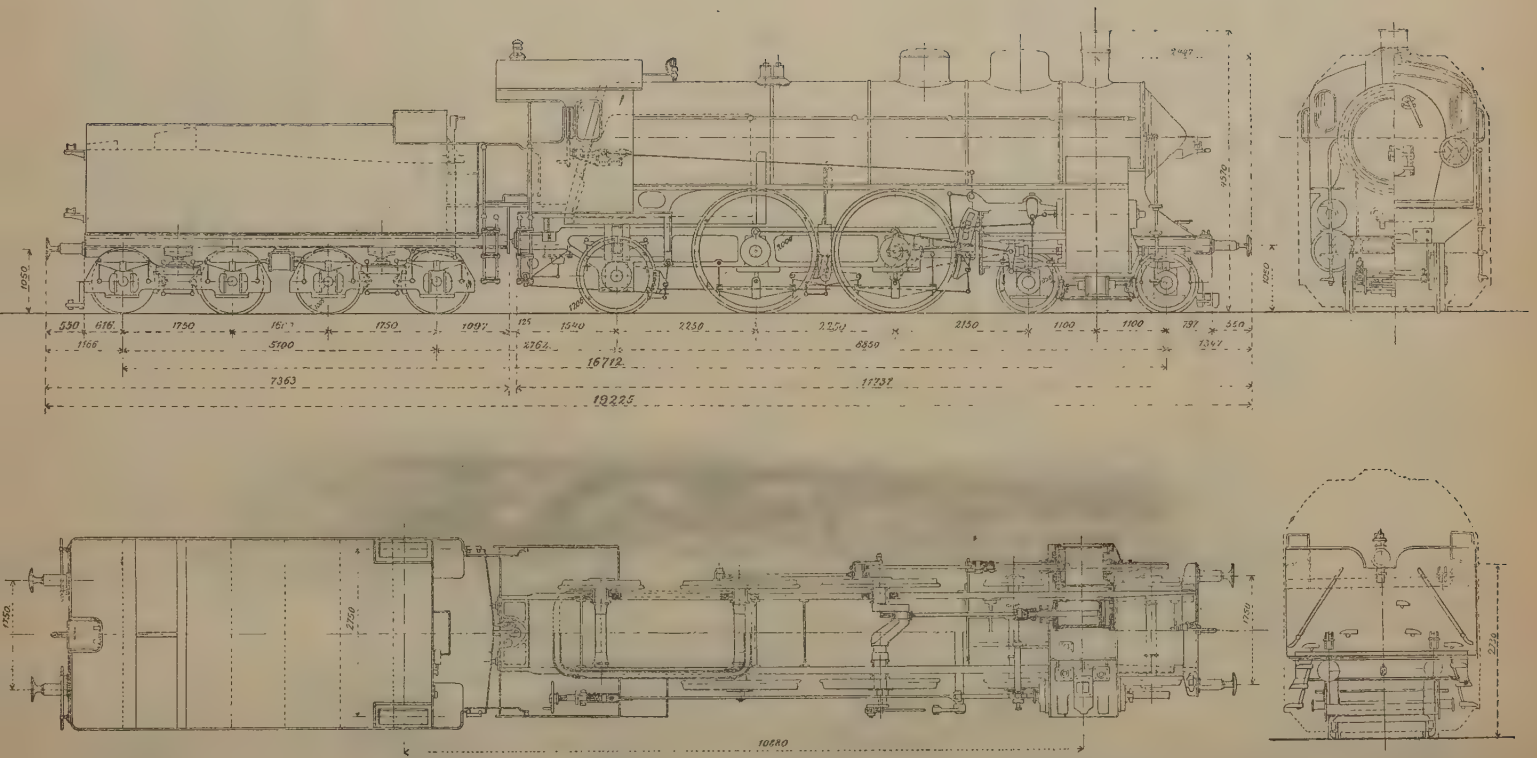


Fig. 11. — Group 2, β. — 2 B 1 Locomotive of the Bavarian State Railway.

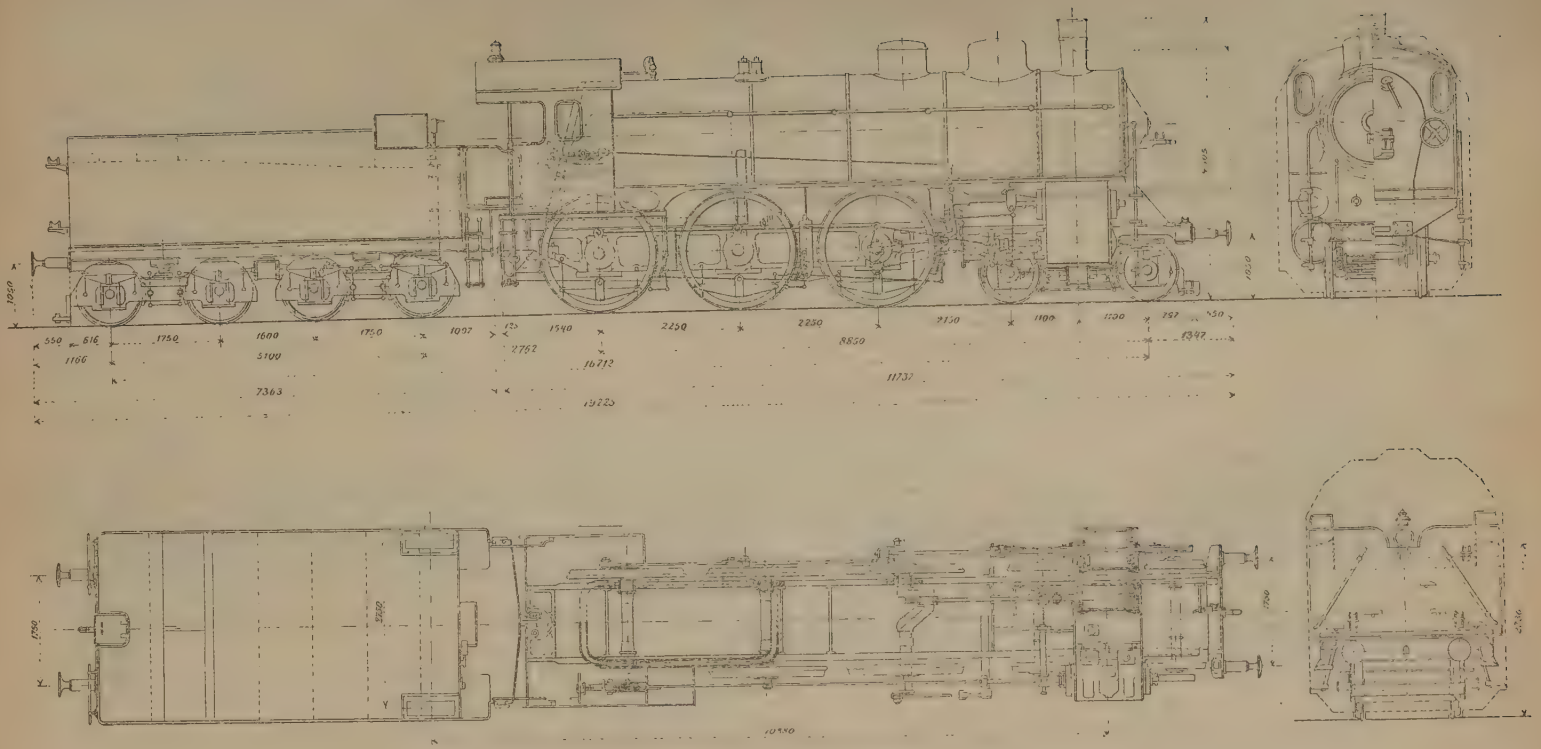


Fig. 13. — Group 2, β. — 2 C Locomotive of the Bavarian State Railway.

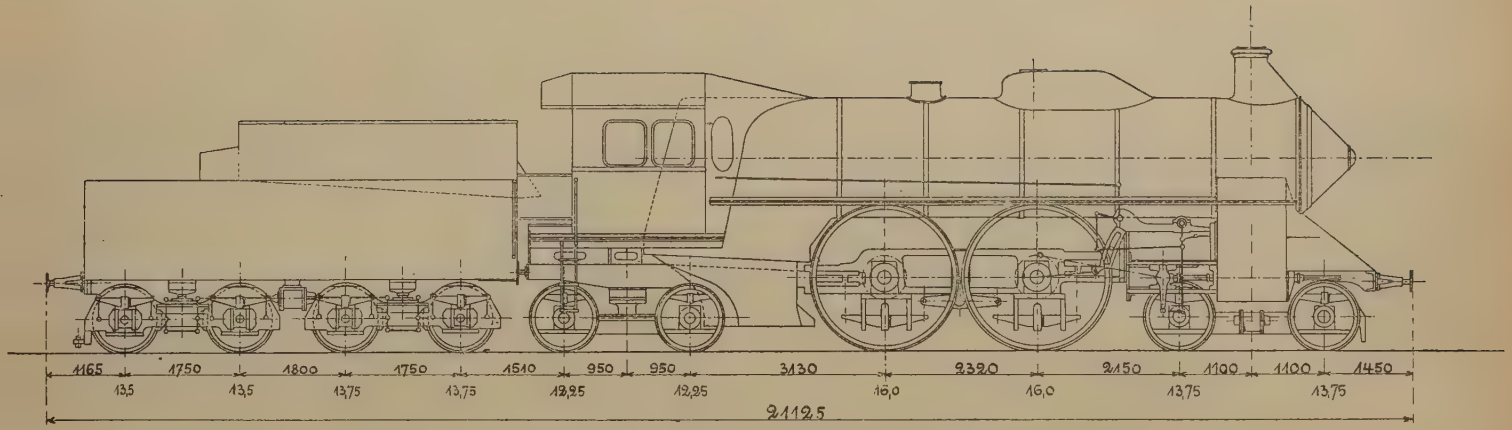


Fig. 12. — Group 2, β. — 2 B 2 Locomotive of the Bavarian State Railway.

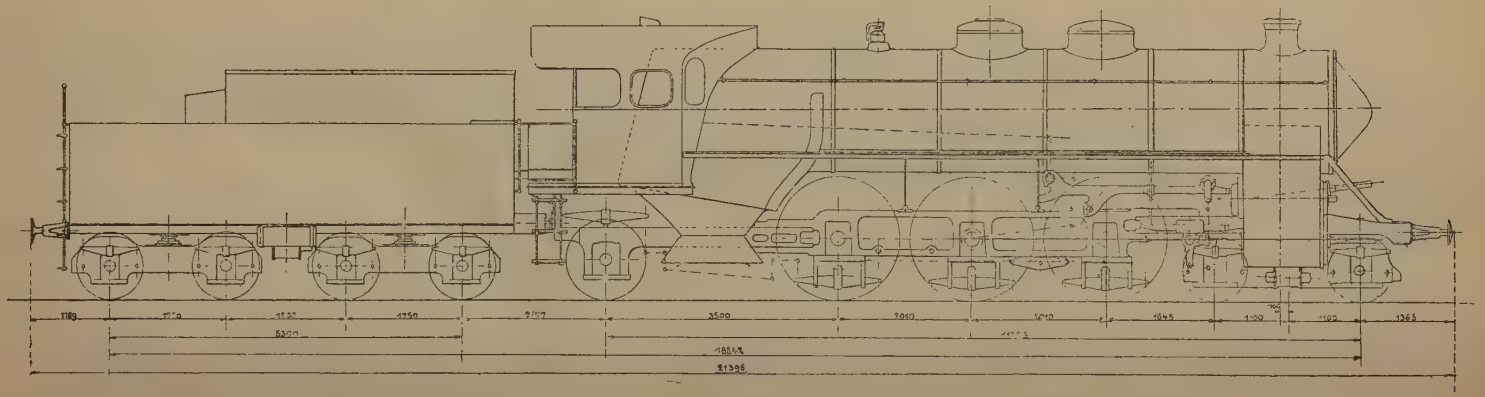


Fig. 14. — Group 2, β. — 2 C 1 Locomotive of the Bavarian State Railway.

Fig. 15.

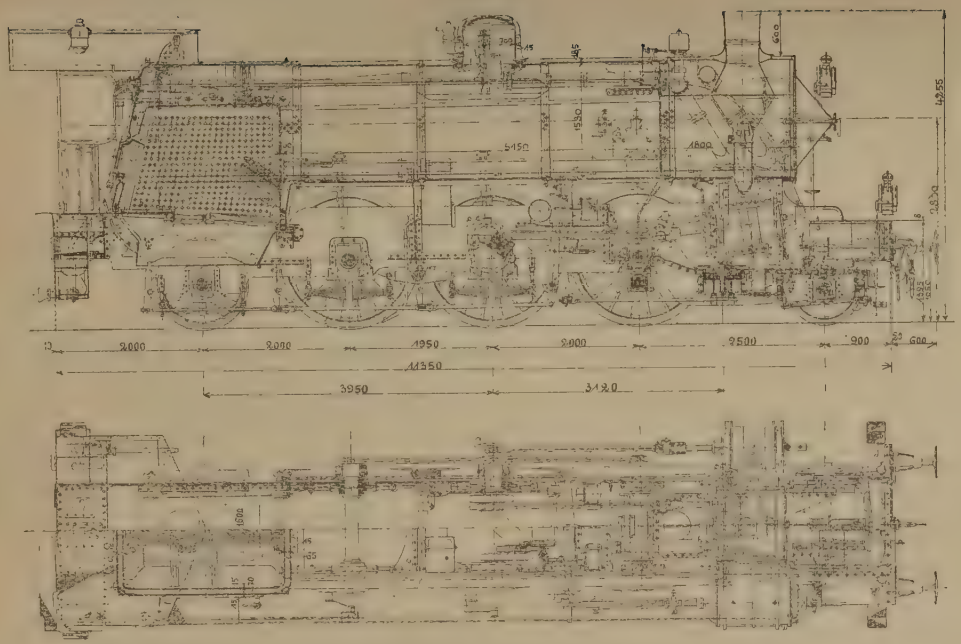


Fig. 16.

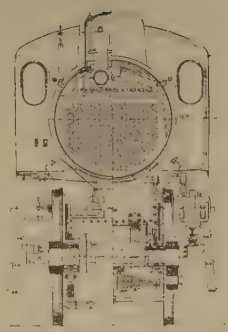


Fig. 18.

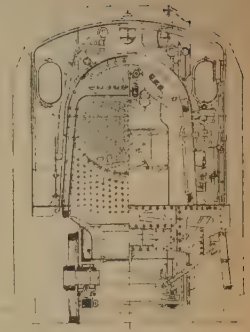


Fig. 19.

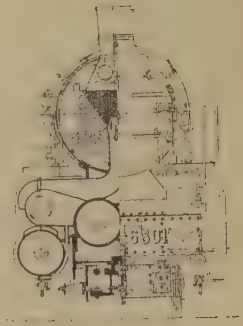


Fig. 17.

Fig. 15 to 19. — Group 2, γ. — 1 C 1 Locomotive of the Italian State Railway.

The frames are bar frames made of wrought iron and consist either of two (2B1, 2C) or of three (2B2, 2C1) parts bolted together. The bogie trucks and carrying axles have enough lateral play to allow the locomotives to run round curves having a radius of 180 metres (9 chains). The driving, carrying and tender axles are all braked. Speeds of up to 150 kiometres (93·2 miles) per hour have been obtained on trial runs with the 2B2 locomotive; this has a special supplementary brake which at the beginning of the braking gives a brake pressure of 114 per cent of the weight of the locomotive and of 130 per cent of the weight of the tender, taken as half loaded.

The 2C wet-steam locomotives have attained speeds up to 110 kilometres (68·4 miles) per hour during trial runs; the 2C superheated-steam locomotives and the 2C1 locomotives have in this way attained speeds of up to 120 kilometres (74·5 miles) per hour. The maximum speed authorized on the Bavarian State Railway, in the regular service, is 100 kilometres (62 miles) per hour.

γ) Italy.

The Italian State Railway owns locomotives of the type 1C1, which are suitable for speeds exceeding 100 kilometres (62 miles) per hour; they are represented in figures 15 to 19. This locomotive is a compound, has a wide fire-box extending over the wheels and a cylindrical wet-steam boiler. The two high-pressure cylinders are on the left side and the two low-pressure cylinders are on the right; in each case one cylinder is inside and one outside, and all have piston valves. All four cylinders act on the middle driving axle.

The frame is a plate frame. The leading carrying axle and the first driving axle are together in one truck, of the Zara type. All axles are braked. The tender has three axles. During trial runs speeds of up to 120 kilometres (74·5 miles) per hour were attained with this locomotive. The maximum authorized speed on the Italian State Railway, in the regular service, is 95 kilometres (59 miles) per hour.

δ) Sweden.

The Swedish State Railway, on which the maximum authorized speed is 90 kilometres (56 miles) per hour, has two types of locomotives which are suited for speeds of over 100 kilometres (62 miles) per hour. These are :

1° One 2B1 locomotive (fig. 20);
2° One 2C locomotive (fig. 21).

These are twin locomotives with Schmidt superheaters; the 2B1 locomotive has inside cylindres and the 2C locomotive outside cylinders. They have piston valves with spring rings. The fire-boxes are wide and extend beyond the frame, but do not extend over the wheels. The frames are bar frames. The bogie-truck frame of the 2B1 locomotive is worth notice; it is made of steel castings. The bogie-truck frames are in both cases outside the wheels. All the wheels of both locomotives are braked, and so are all the tender wheels. The tenders have three axles (figs 22 to 25). The tender of the 2B1 locomotive is to be replaced by a four-axle tender. At the front end of the front end of the tender there is a wall, put

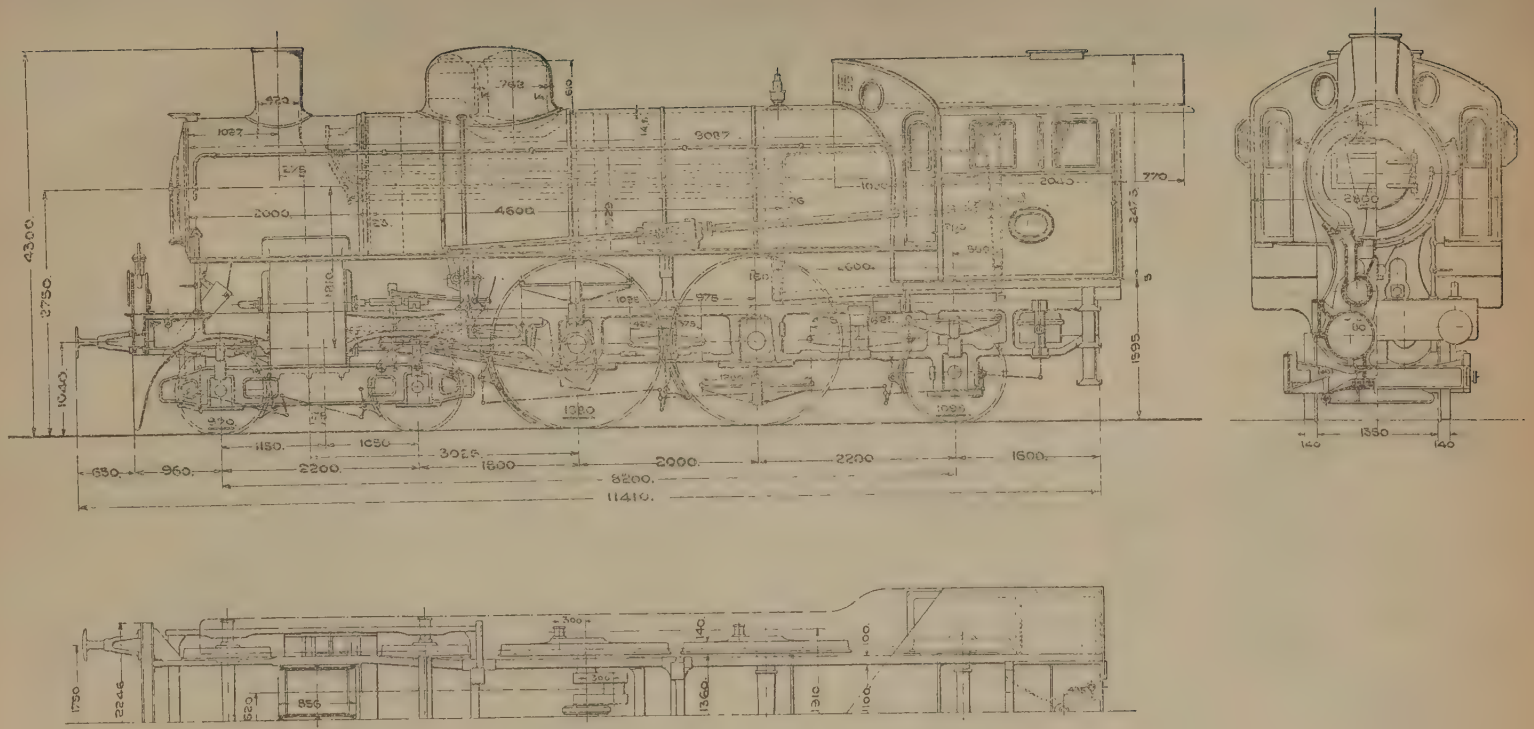


Fig. 20. — Group 2, 3. — 2 B 1 Locomotive of the Swedish State Railway.

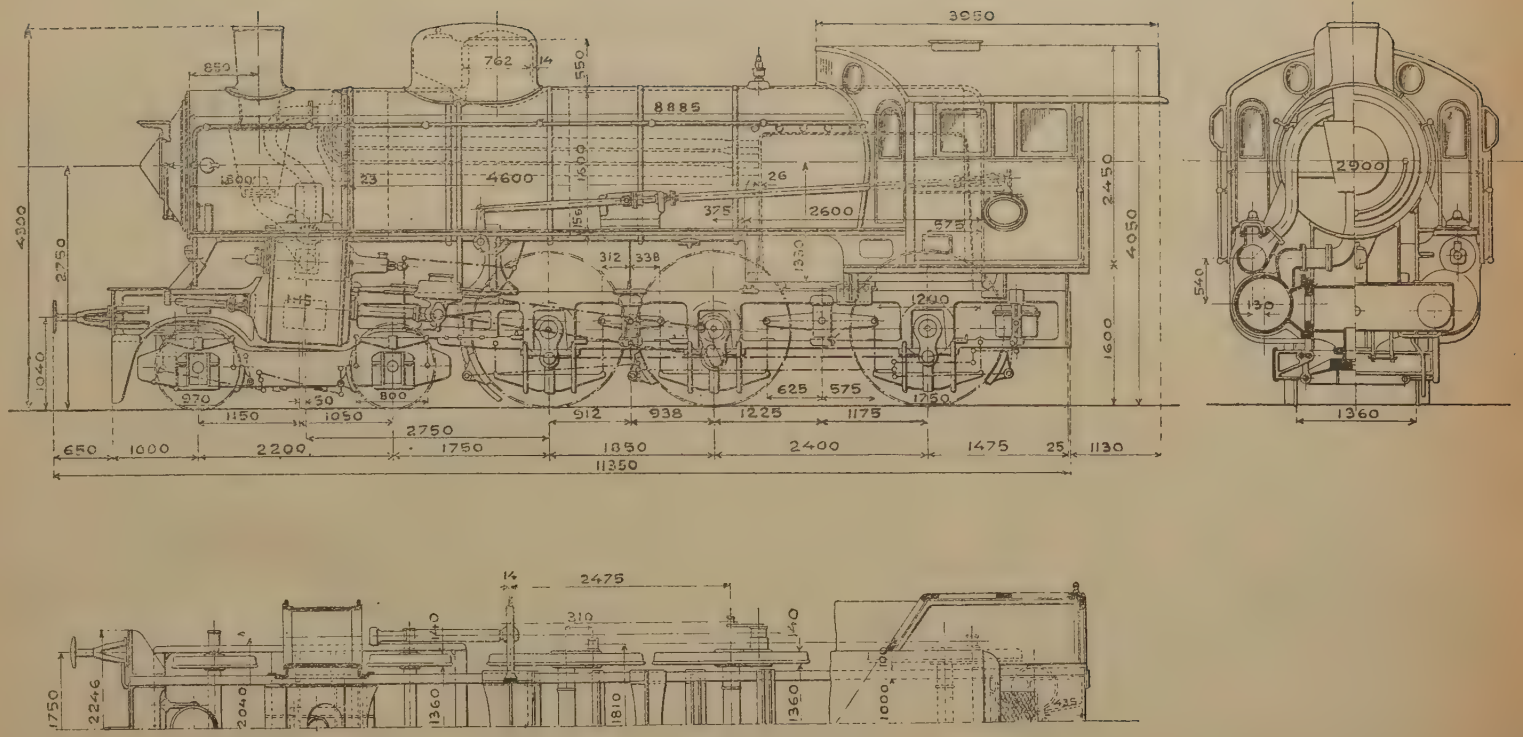
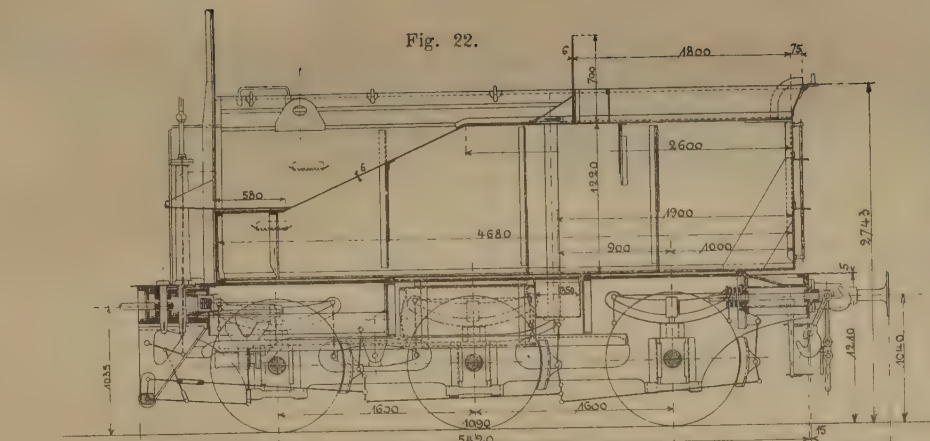


Fig. 21. — Group 2, δ. — 2 C Locomotive of the Swedish State Railway.

Fig. 22.



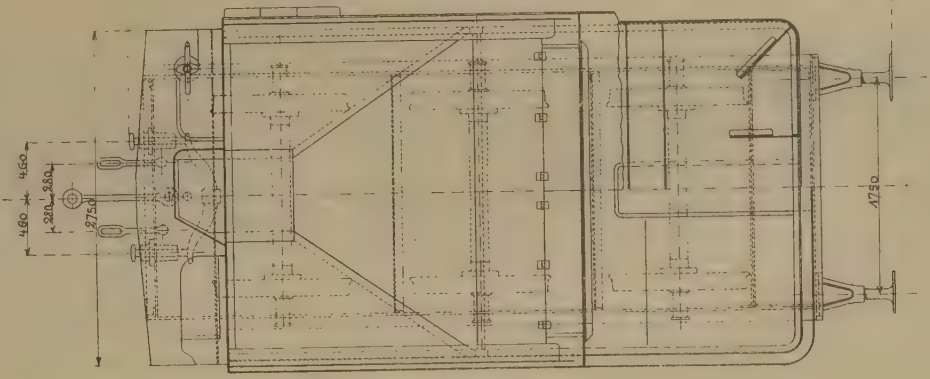
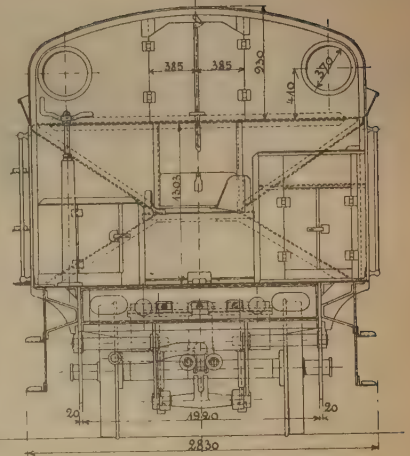


Fig. 23.

Fig. 24.



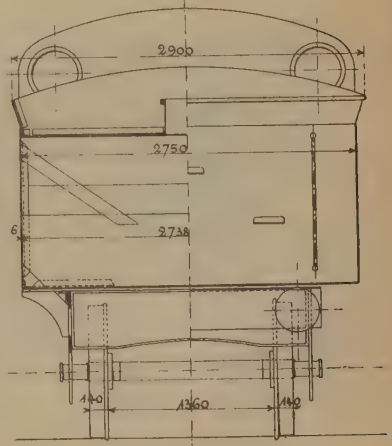


Fig. 25.

Figs. 22 to 25. — Group 2, 6. — Tender of the locomotives of the Swedish State Railway.

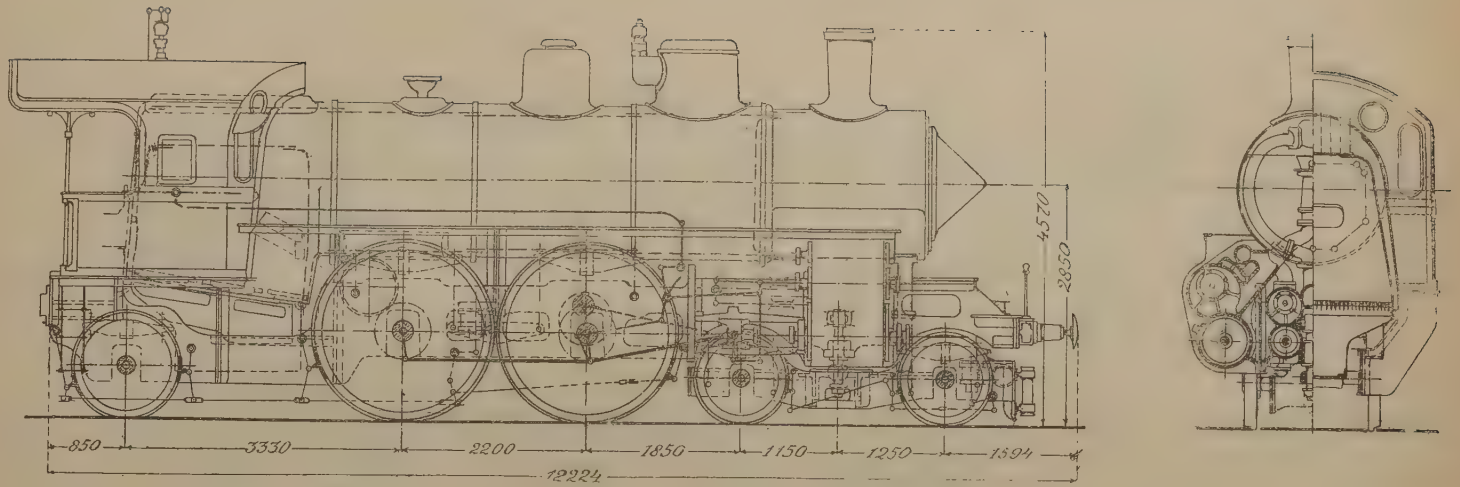


Fig. 26. — Group 2, ε. — 2 B 1 Locomotive of the Hungarian State Railway.

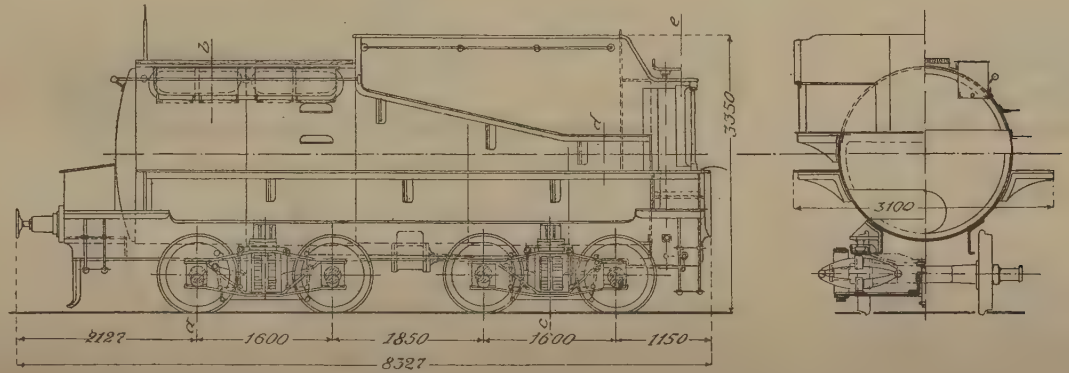


Fig. 27. — Groupe 2, ε. — Tender of the 2 B 1 locomotive of the Hungarian State Railway.

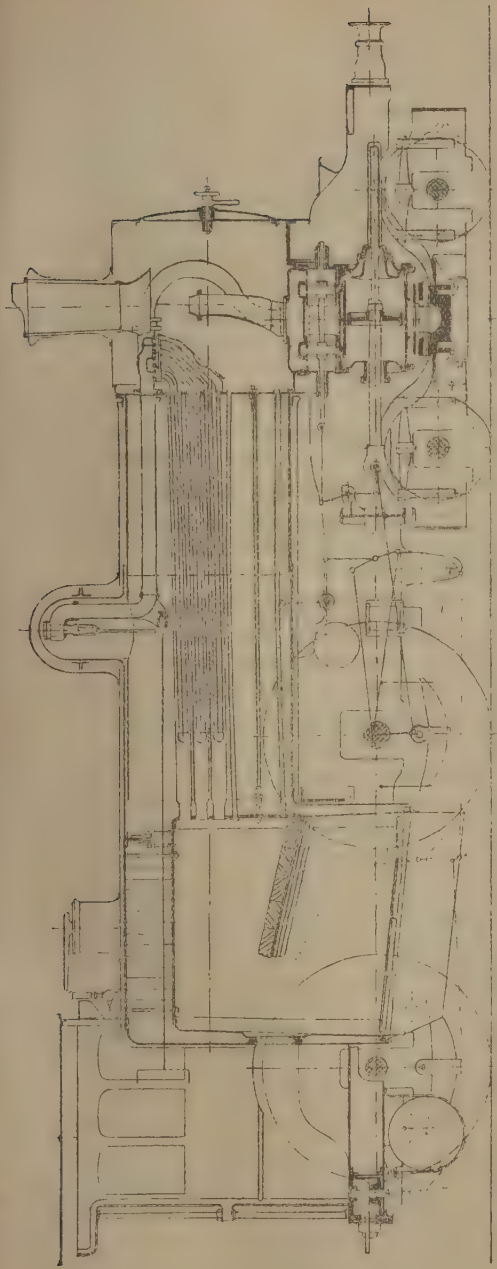


Fig. 28. — Group 3, α. — 2 B Locomotive of the Belgian State Railway.

up to protect the locomotive crew in case of bad weather.

ε) Hungary.

The Hungarian State Railway has thirty four locomotives of the 2 B 1 type, which are able to run at speeds exceeding 100 kilometres (62 miles) per hour; during trial runs speeds of up to 143 kilometres (88.9 miles) per hour were attained. The maximum authorized speed on the railway in question, in regular service, is 100 kilometres (62 miles) per hour.

These locomotives (fig. 26) are fourcylinder compounds, with wet-steam boiler. The fire-box has a wide grate which extends beyond the plate frame and the wheels. All the four cylinders act on the first driving axle; all the axles of the locomotive and of its four-axled tender are braked. The tender (fig. 27) is of the Vanderbilt type, with cylindrical water tank; its bogie trucks have bar frames of the American (diamond) type.

b) Locomotives of group 3.

The chief dimensions and particulars of the locomotives included under this head are given in appendix 3.

α) Belgium.

There are three varieties of locomotives running on the Belgian State Railway, which are

capable of exceeding speeds of 100 kilometres (62 miles) per hour, and which are used for the purpose in exceptional cases :

1° A 2 B type; two hundred and fifty of these exist, of varying designs; the most recent is shown in fig. 28;

2° A 2 B 1 type; twelve of them exist (fig. 29);

3° A 2 C type; there are forty-two of them (figs. 30 and 31).

All the three types have the same tender (fig. 32).

The 2 B locomotive is a non-compound and has two inside cylinders; the 2 B 1 locomotive is a compound and has outside cylinders. The 2 C locomotive is a non-compound and has four cylinders; these four cylinders are placed side by side and all of them act on the first driving axle. All the three types use superheated steam and are equipped with Schmidt smoke-tube superheaters; they have piston valves with spring rings and have deep fire-boxes, some of them being rather long, which are placed within the plate frame. All the carrying and driving wheels of the three types are braked. The water tank of the tender extends below to between the frame plates.

β) **Germany.**

The Baden State Railway has three classes of locomotive which are capable of running at speeds exceeding 100 kilometres (62 miles) per hour :

1° Thirty-six locomotives of type 2 B (figs. 33 to 36);

2° Seventeen locomotives of type 2 B 1 (figs. 37 to 40);

3° Fifteen locomotives of type 2 C 1 (figs. 41 to 44).

Their tenders are shown in figures 45 to 48.

The 2 B locomotives are non-compounds with wet-steam boilers, and have two inside cylinders with balanced flat slide valves; the fire-box is inside the frame and only the driving axles are braked. The front of the smoke-box and the front of the cab are tapered to form wind cutters on some of the locomotives only. The 2 B 1 and 2 C 1 types are four-cylinder compounds; the former use wet steam and the latter superheated steam (Schmidt smoke-tube superheater). In both types all the four cylinders are placed side by side (high-pressure cylinders inside), and act on the same driving axle (the first in the case of the 2 B 1 type, the second in that of the 2 C 1 type).

The older 2 B 1 locomotives have flat slide valves for the low-pressure cylinders; the newer ones, as well as the 2 C 1 locomotives, have piston valves with spring rings for all the cylinders.

Both types have wide grates extending over the wheels. All axles of both types are braked. The 2 B 1 locomotives have plate frames; the 2 C 1 locomotives have welded bar frames made in one piece.

The locomotive tenders have four axles and bogies of the diamond type. The tender of the 2 B locomotives, which is not represented in the figures, is very similar to that of the 2 B 1 locomotives (figs. 45 and 46); it is only a little smaller, taking 15 cubic metres (3,300 English gallons) of water, while the 2 B 1 tender takes 20 cubic metres (4,400 English gallons).

The 2 C 1 tender (figs. 47 and 48) is of the Gölsdorf type, with side tanks and narrow coal bunkers.

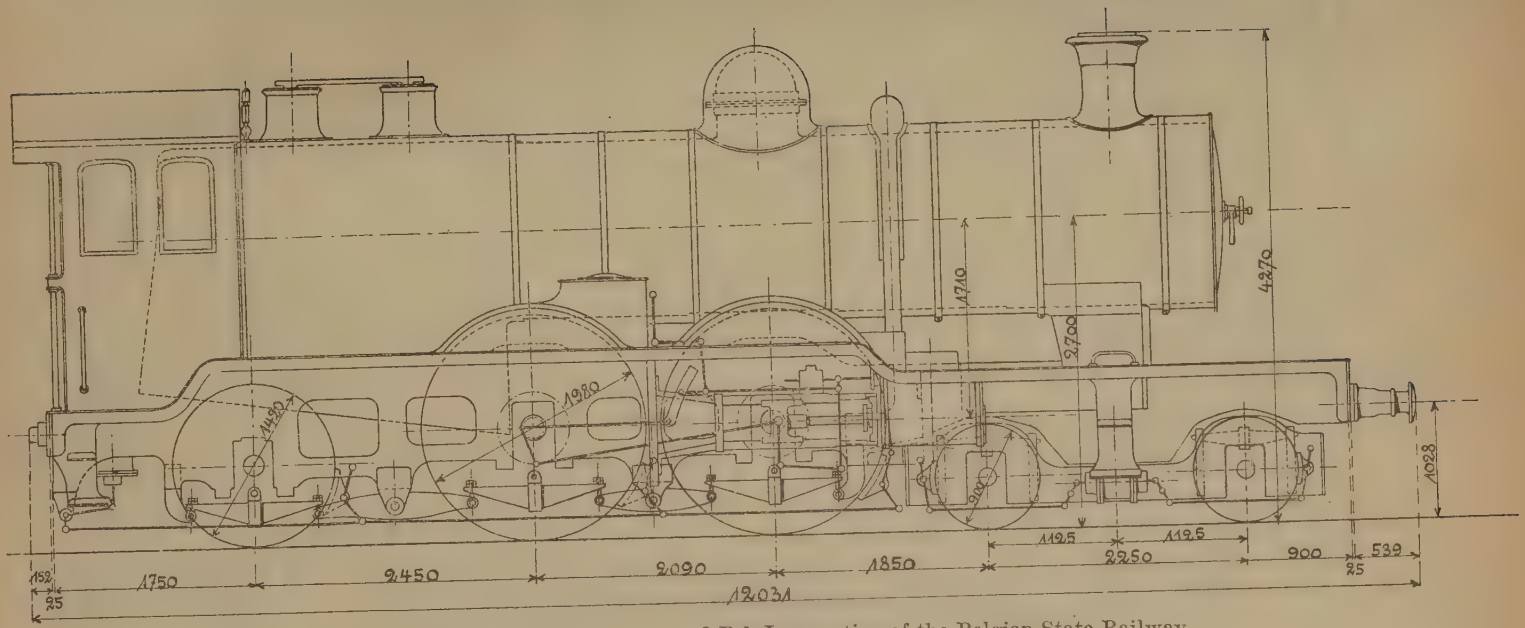
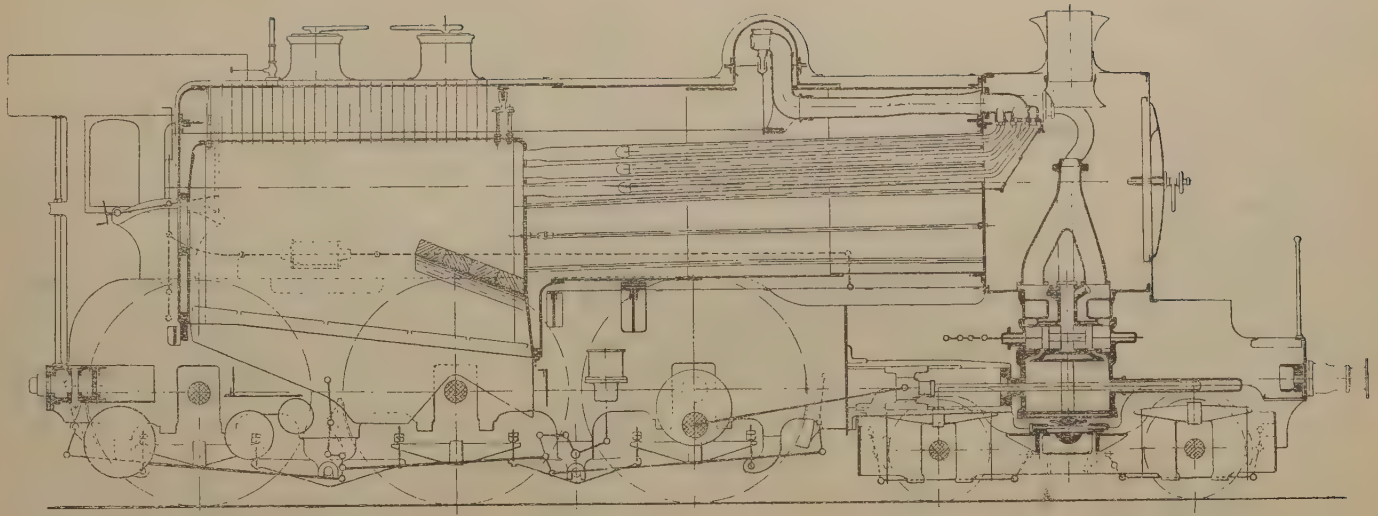


Fig. 29. — Group 3, α. — 2 B 1 Locomotive of the Belgian State Railway.

Fig. 30.



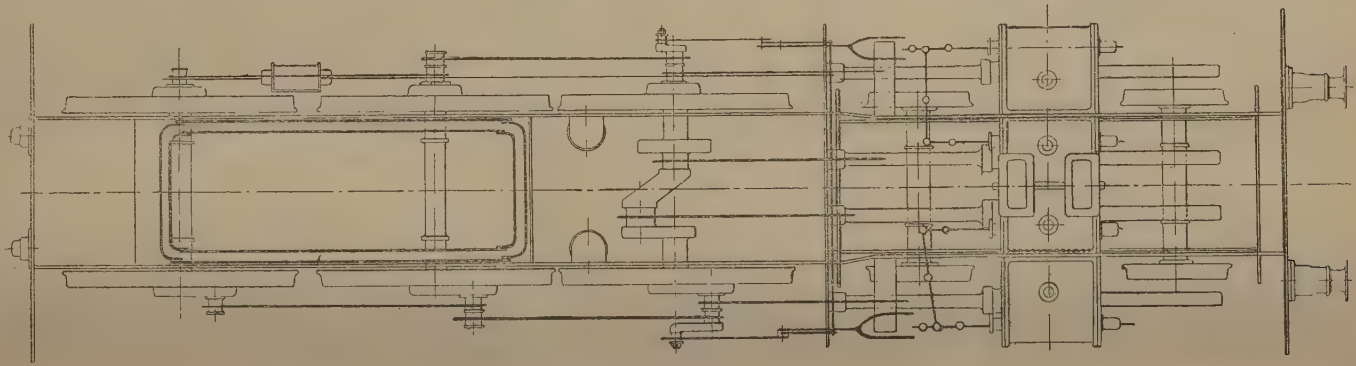


Fig. 31.

Figs. 30 and 31. — Group 3, *a*. — 2-C Locomotive of the Belgian State Railway.

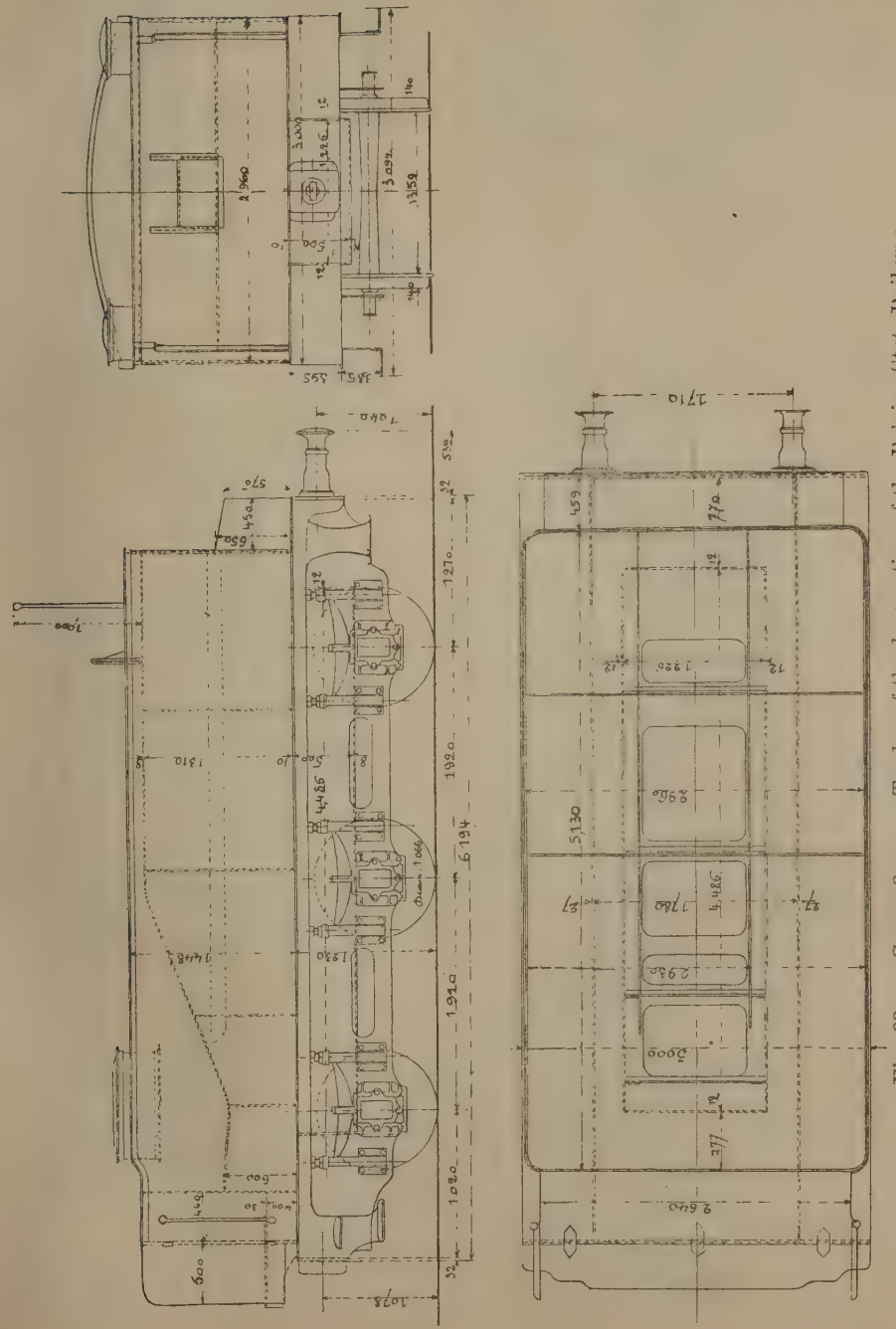
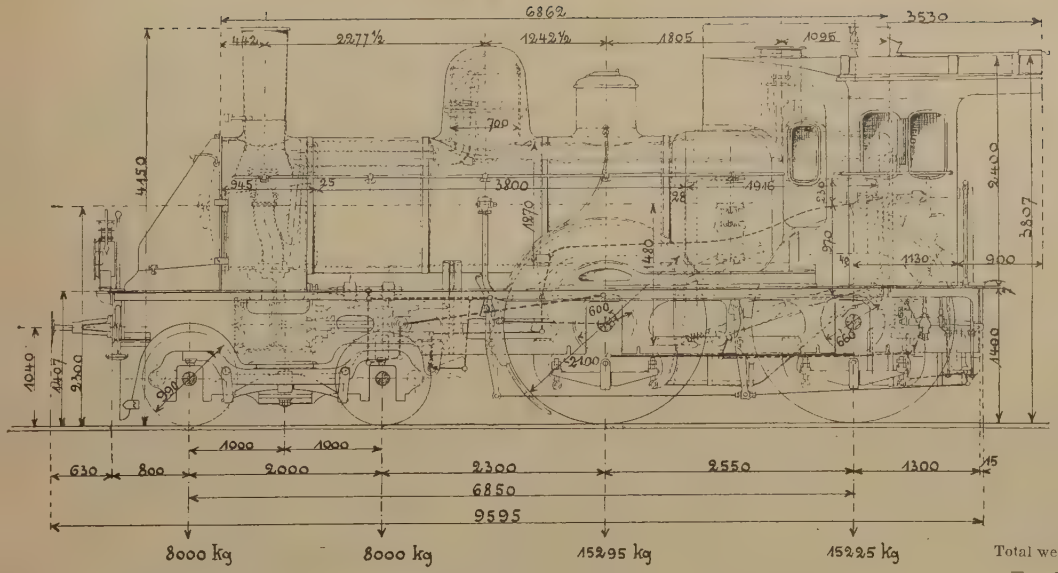


Fig. 32. — Group 3, a. — Tender of the locomotive of the Belgian State Railway.

Fig. 33.



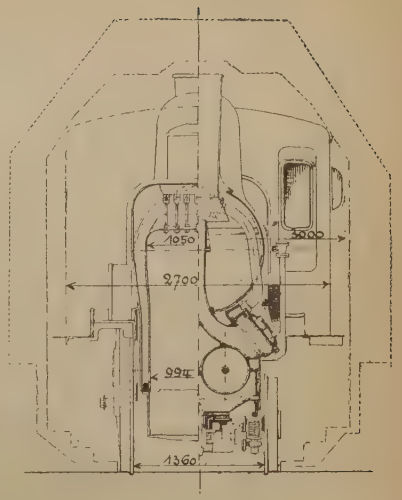


Fig. 34.

Total weight in working order, . . . 46.520 kilogrammes (102,560 lb.)
— — empty . . . . . 42,470 — (93,630 lb.)

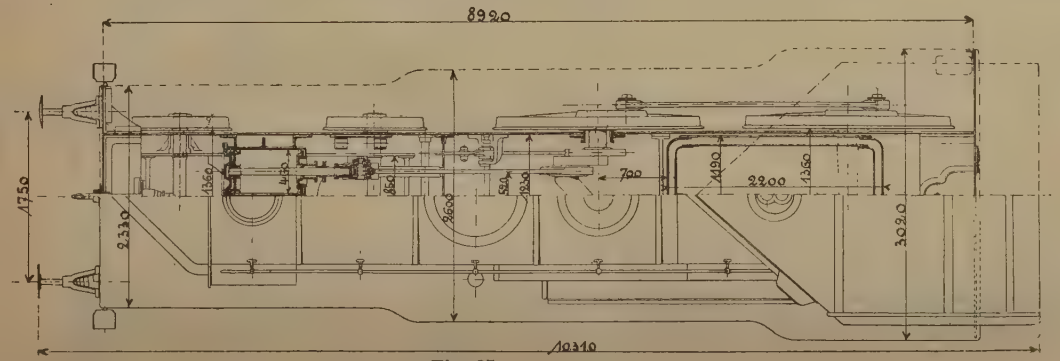


Fig. 35.

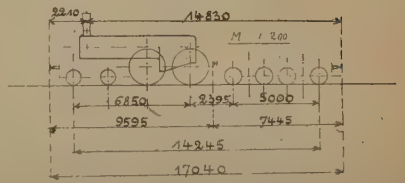
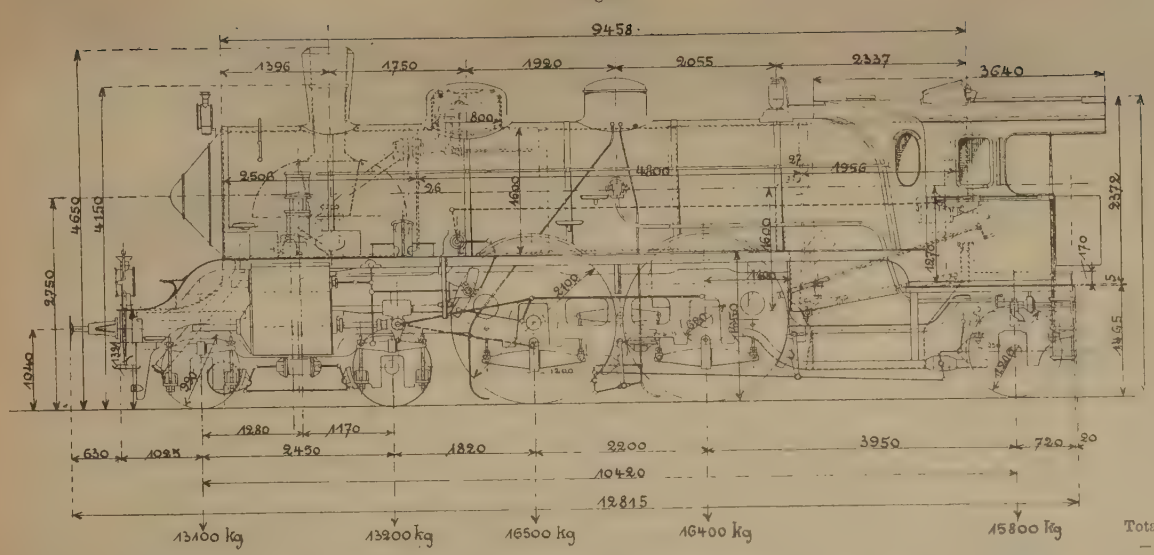


Fig. 36.

Figs. 33 to 36. — Group 3 $\frac{6}{5}$. — 2 B Locomotive of the Baden State Railway.

Fig. 37.



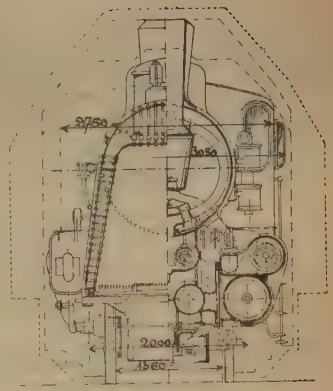


Fig. 38.

Total weight in working order... 75,000 kg. (165,350 lb.)
— — empty..... 68,000 — (149,900 lb.)

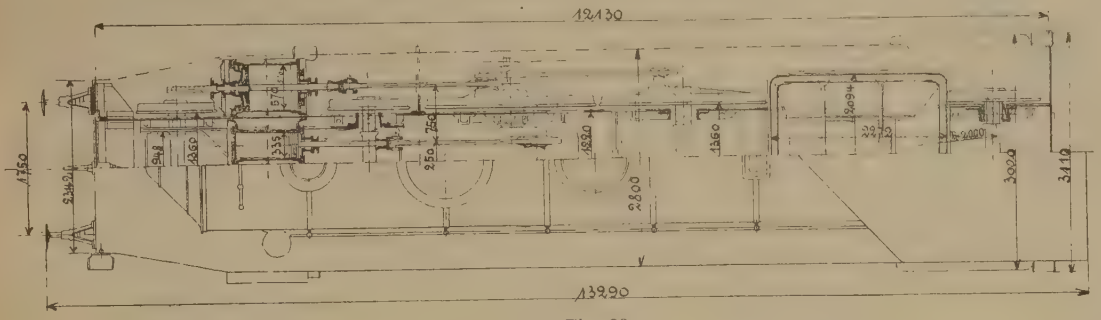


Fig. 39.

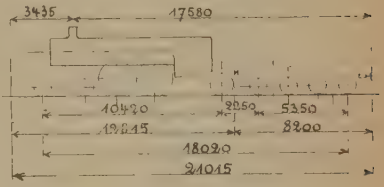
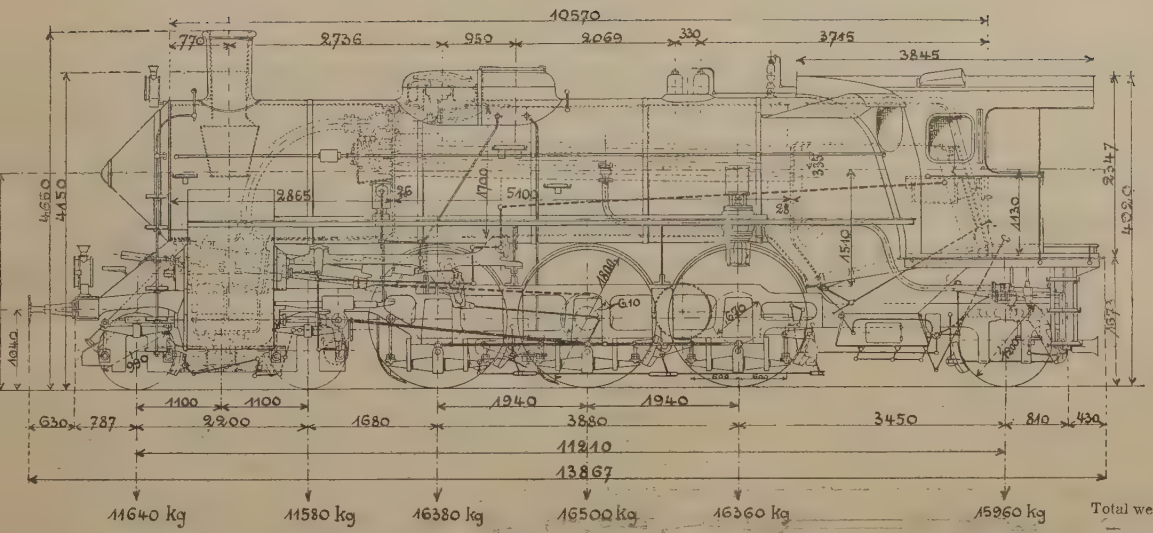


Fig. 40.

Figs. 37 to 40. — Group 3, β. — 2 B 1 Locomotive of the Baden State Railway.

Fig. 41.



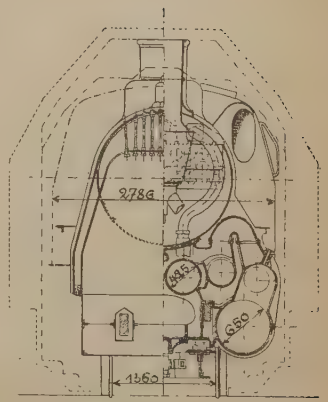


Fig. 43.

Total weight in working order... 88,420 kilograms (194,930 lb.)
— — empty..... 81,100 — (178,800 lb.)

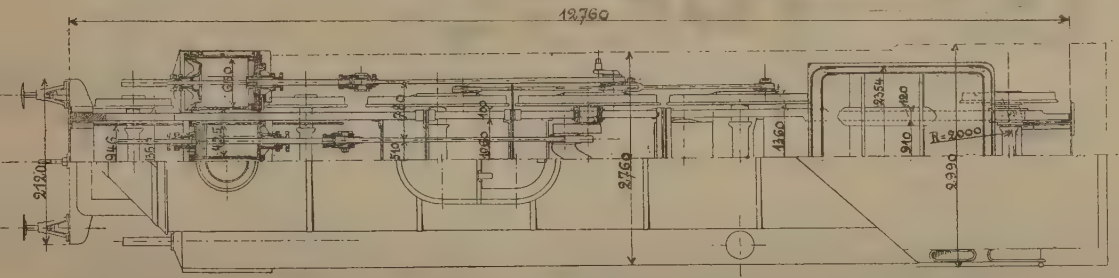


Fig. 42.

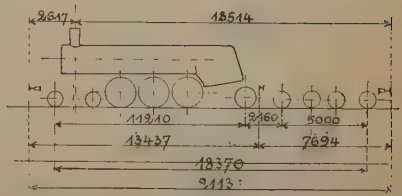


Fig. 44.

Figs. 41 to 44. — Group 3, β. — 2 C 1 Locomotive of the Baden State Railway.

Fig. 45.

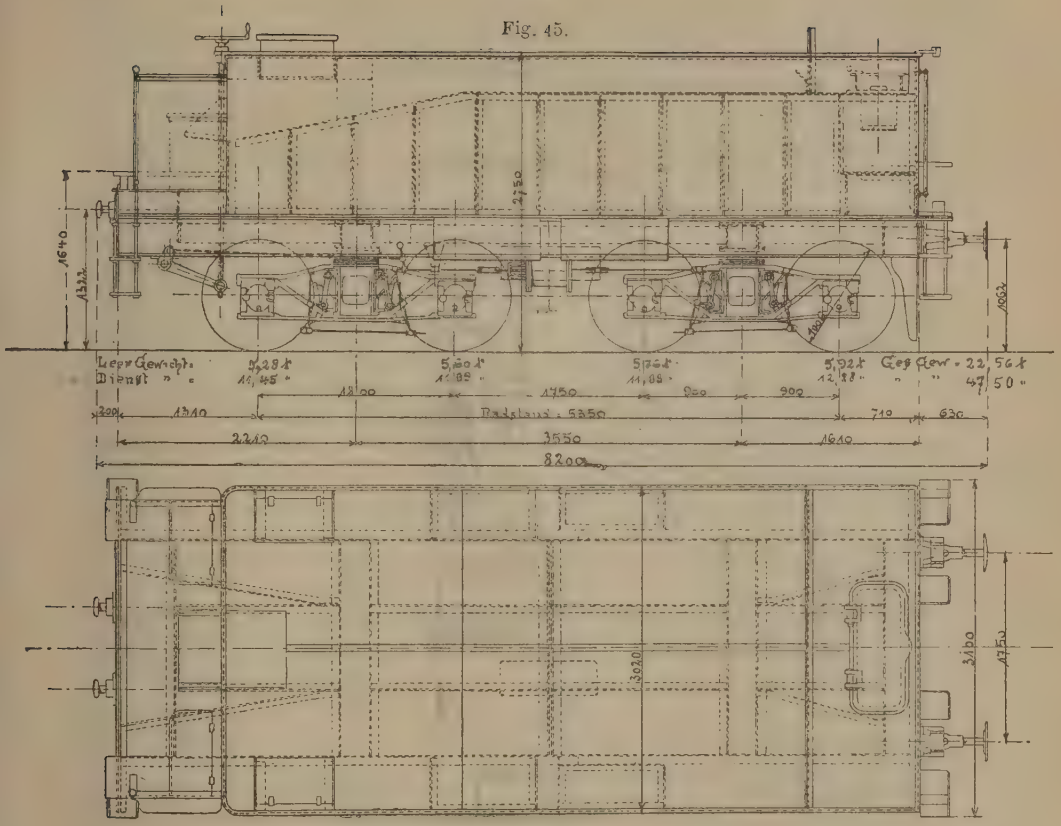


Fig. 46.

Figs. 45 and 46. — Group 3, β.
Tender of the 2 B 1 locomotive (figs. 37 to 40) of the Baden State Railway.

γ) France.

1. — *Paris-Lyons-Mediterranean Railway.*

The Paris-Lyons-Mediterranean Railway owns four hundred and forty-nine locomotives which are capable of running at speeds exceeding 100 kilometres (62 miles) per hour. Many of the designs only show minor differences; we will accordingly only consider the following six types more in detail :

1° One locomotive of type 1 B (figs. 49 and 50);

2° Ninety-six locomotives of type 2 B, older (figs. 51 and 52);

3° One hundred and sixty-two locomotives of type 2 B, newer (figs. 53 and 54);

Fig. 47.

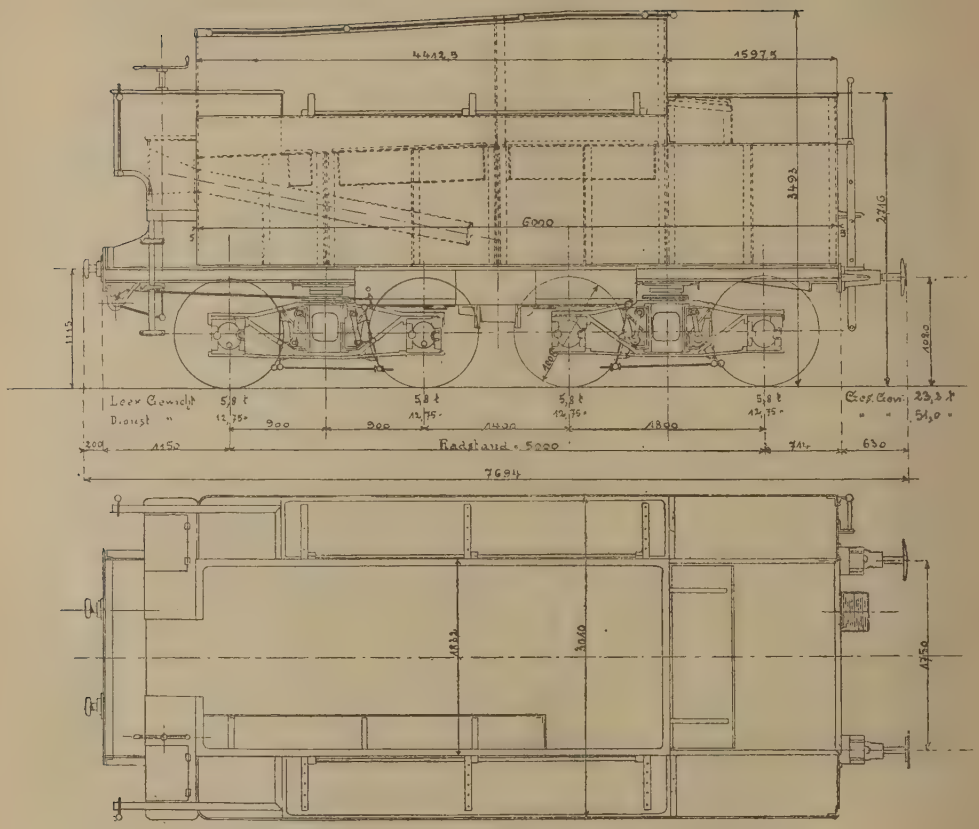


Fig. 48.

Figs. 47 and 48. — Group 3, β.
Tender of the 2 C 1 locomotive of the Baden State Railway.

4° Ten locomotives of type 2 B 1, older (figs. 55 and 56);

5° Twenty locomotives of type 2 B 1, newer (figs. 57 and 58);

6° One hundred and sixty locomotives of type 2 C (figs. 59 and 60).

1° The 1 B locomotive uses double expansion; the four cylinders act on two driving axles, on the de Glehn system; the flat slide valves are not balanced; there is a plate frame and a narrow deep firebox, and the last ring of the barrel is tapered. The carrying axles have a lateral play of 16 millimetres ($^5/_8$ inch) on each side. The driving axles are braked.

2° The older 2 B locomotive is a non-compound and has two outside cylinders. The flat slide valves are also not balanced; there is a plate frame and a narrow deep fire-box, with raised crown: the driving axles alone are braked.

3° The newer 2 B locomotives is a four-cylinder compound with de Glehn drive and plate frame; it is very fully equipped with devices for reducing the air resistance (wind cutters), at the front of the smoke-box, the chimney, the dome and the cab. The flat slide valves are not balanced. The driving axles alone are braked.

4° The older 2 B 1 locomotives were supplied by an American works, and show all the American characteristics, such as a bar frame with staying at the smoke-box, a high and exposed boiler, etc. The locomotive is a non-compound and has two outside cylinders, piston valves, a fire-box which stands on the frame between the wheels and has an inclined crown, and a cylindrical barrel. The two driving axles and the trailing carrying axle are braked.

5° On the other hand, the newer 2 B 1 locomotives are of purely European type. The four cylinders are nearly side by side over their whole length, high-pressure outside, low-pressure inside; they have piston valves and act on separate axles. The deep fire-box has a grate which is considerably inclined; the barrel of the boiler is cylindrical. All the five axles are braked.

6° The 2 C locomotive is of very similar design; here also there are piston valves and all axles are braked.

Of the tenders, that used with the 1 B locomotive (figs. 49 and 50) has four axles; it is shown in figures 61 to 63. Bogie trucks are not used; the four axles are placed very close together in one frame, so that the total wheelbase is not quite 4 metres (13 ft. 1 $^1/_2$ in.). The tenders used with all the other locomotives described have three axles. One of the more recent designs is shown in figures 64 to 66; this is used with the following locomotives.

3° 2 B type (figs. 53 and 54);
5° 2 B 1 type (figs. 57 and 58);
6° 2 C type (figs. 59 and 60).

2. — *French State Railway.*

The French State Railway has ten locomotives which were designed and are used for speeds exceeding 100 kilometres (62 miles) per hour; they are of the 2 B 1 type and have three-axled tenders (fig. 67). They are double-expansion compounds with four cylinders and de Glehn drive; the flat slide valves are only balanced in the case of the high-pressure cylinders; the deep fire-box has a grate which is considerably inclined and the barrel of the boiler is cylindrical. The driving axles and the trailing carrying axle are braked. The tender is equipped with Ramsbottom scoop.

3. — *Midi Railway.*

The Midi Railway states that it has sixty-eight locomotives able to run at speeds exceeding 100 kilometres (62 miles) per hour; they are of the following three types :

1° Thirty-four locomotives of type 2 B (fig. 68);

2° Thirty locomotives of type 2 B 1 (fig. 69);

3° Four locomotives of type 2 C 1 (fig. 70).

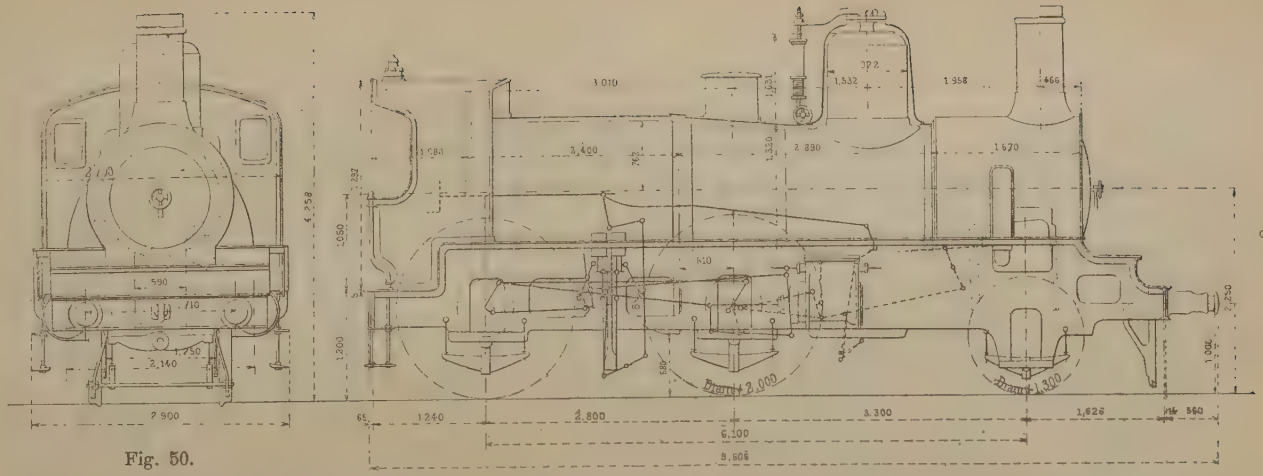


Fig. 49.

Fig. 50.

Figs. 49 and 50. — Group 3, γ, 1. — 1 B Locomotive of the Paris-Lyons-Mediterranean Railway.

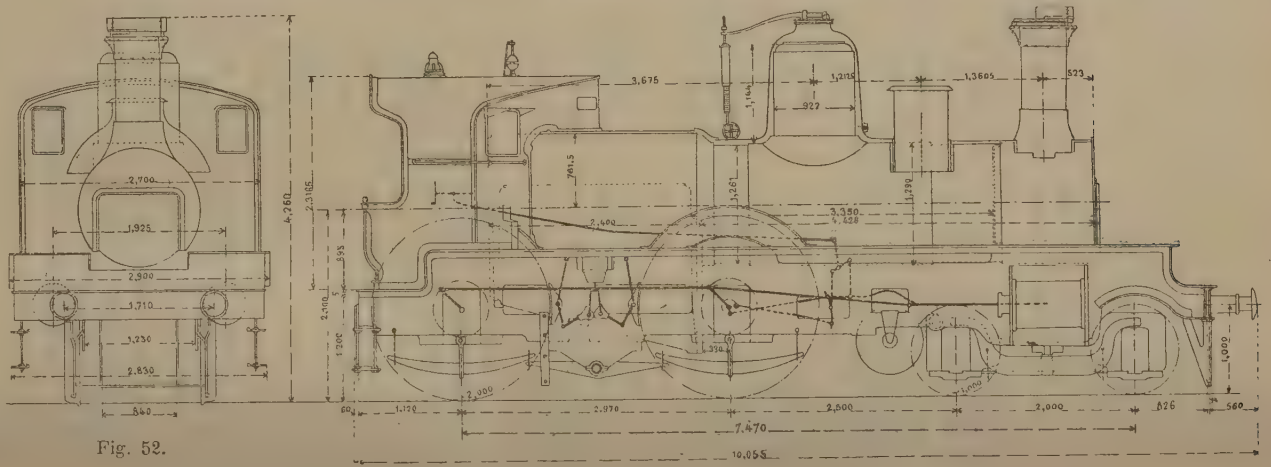


Fig. 51.

Fig. 52.

Figs. 51 and 52. — Group 3, γ, 1. — 2 B Locomotive of the Paris-Lyons-Mediterranean Railway.

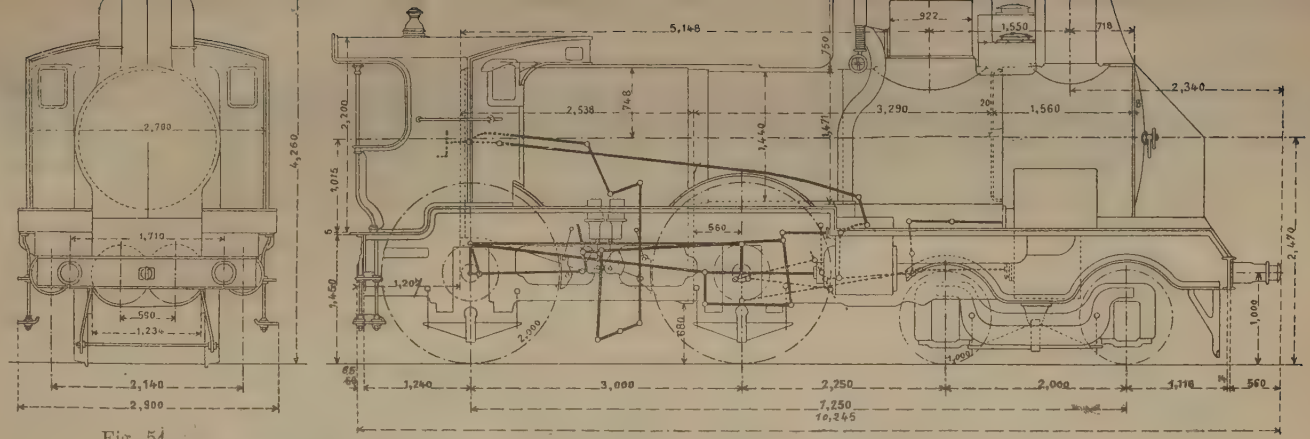


Fig. 53.

Fig. 54.

Figs. 53 and 54. — Group 3, γ, 1. — 2 B Locomotive of the Paris-Lyons-Mediterranean Railway.

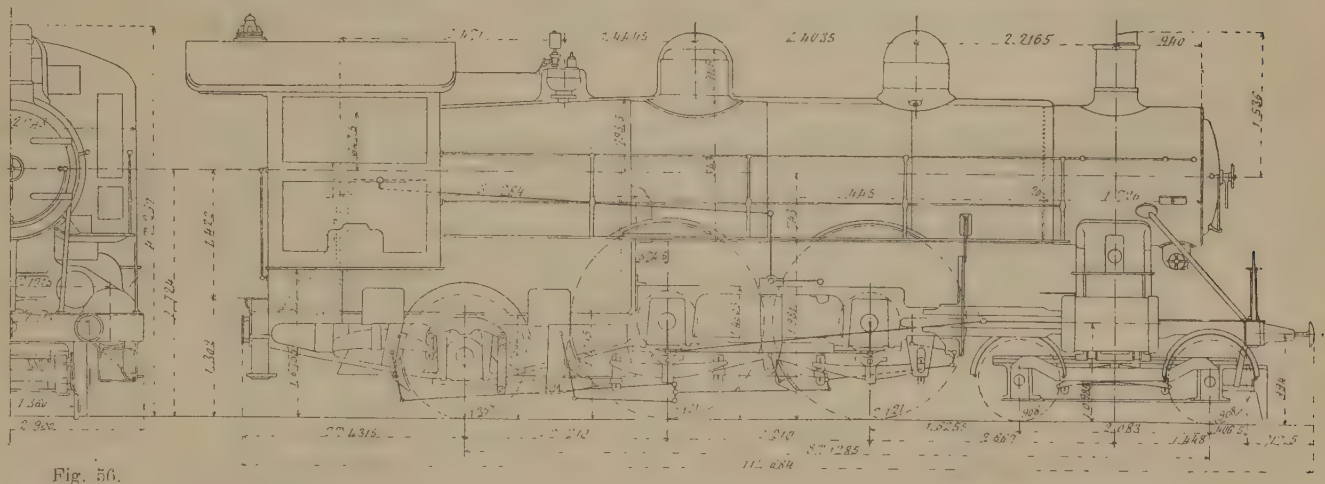


Fig. 55.

Fig. 56.

Figs. 55 and 56. — Group 3, γ, 1. — 2 B 1 Locomotive of the Paris-Lyons-Mediterranean Railway.

Fig. 57.

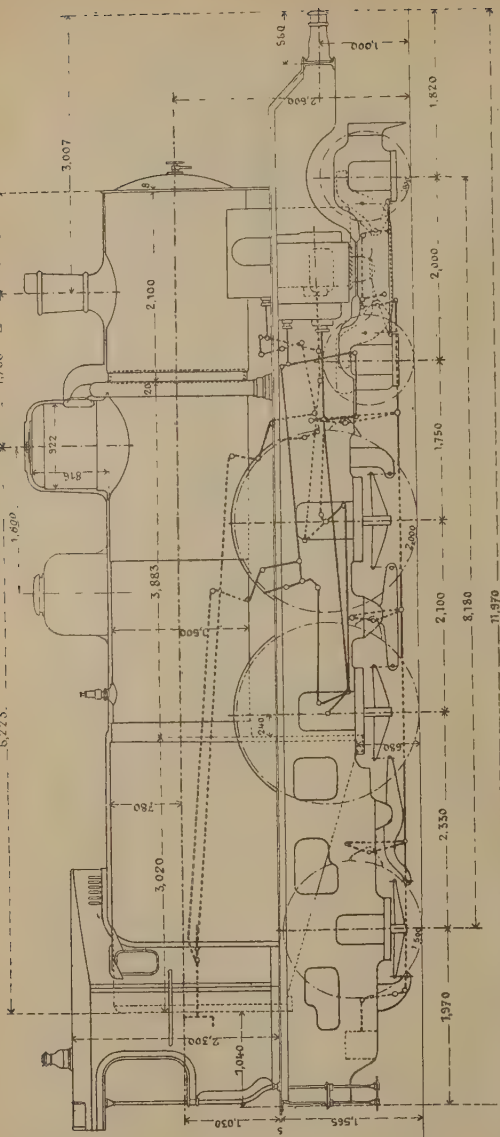


Fig. 58.

Figs. 57 and 58. — Group 3, 7, 1. — 2 B 1 Locomotive of the Paris-Lyons-Mediterranean Railway.

Fig. 59.

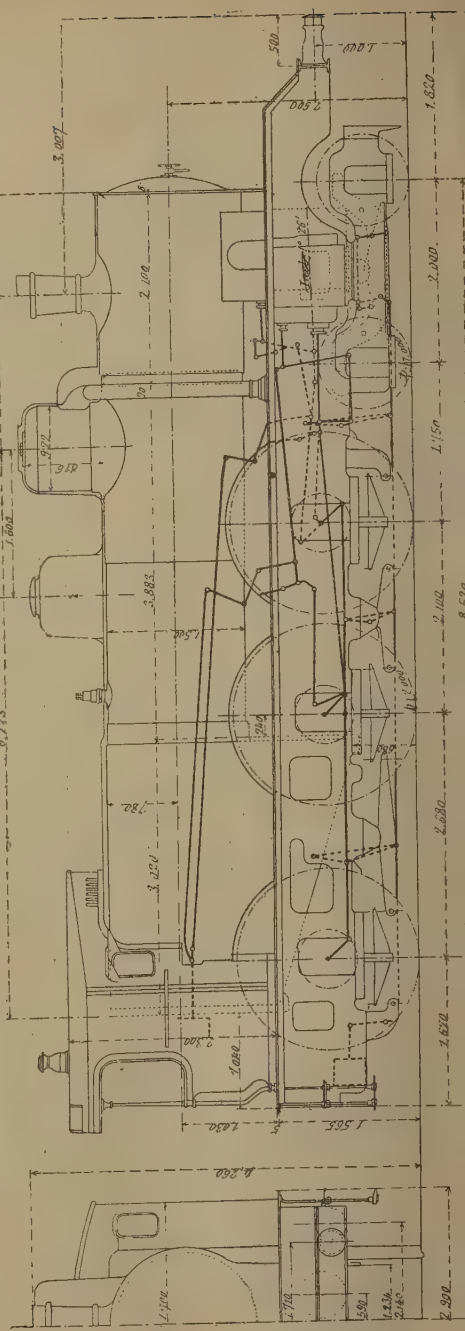


Fig 60.

Fig. 61.

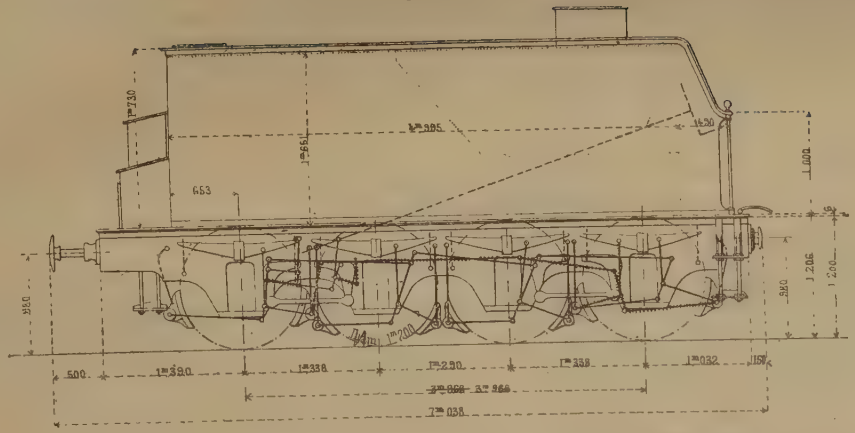


Fig. 62.

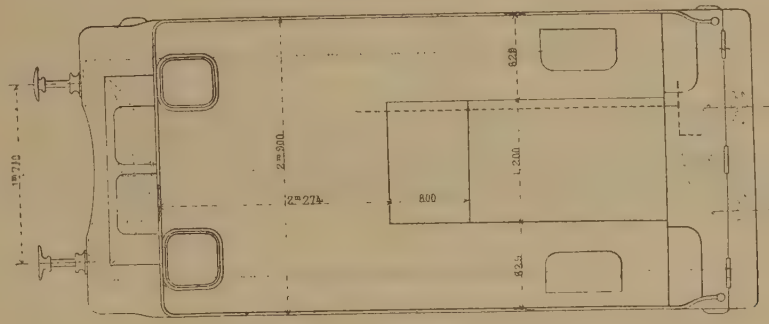
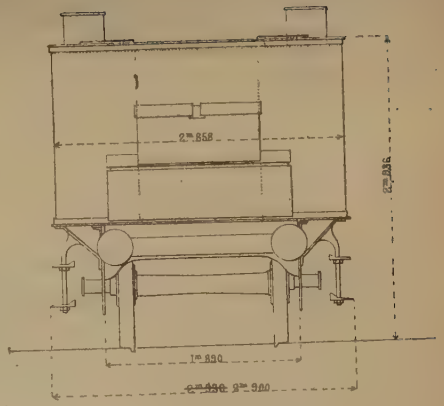
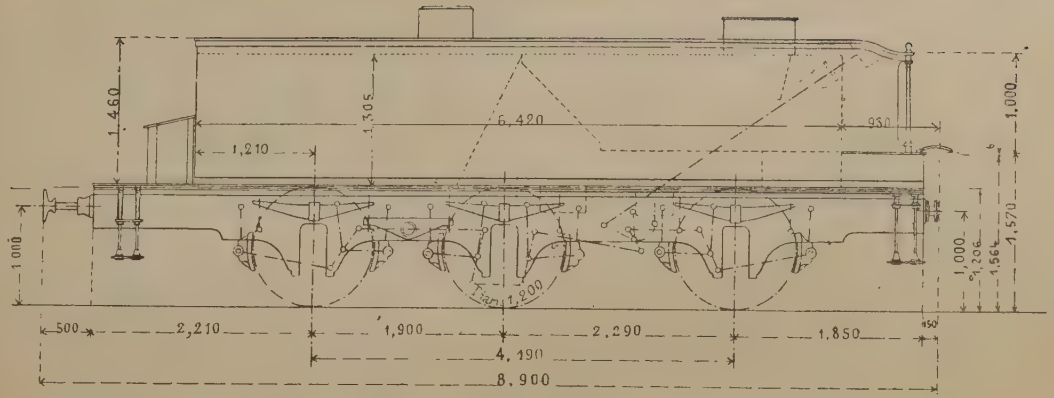


Fig. 63.



Figs. 61 to 63. — Group 3, 7 1. — Tender of the 1 B locomotive of the Paris-Lyons-Mediterranean Railway.

Fig. 64.



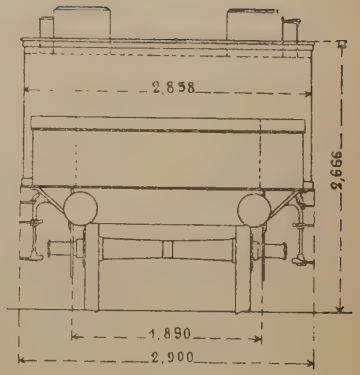


Fig. 66.

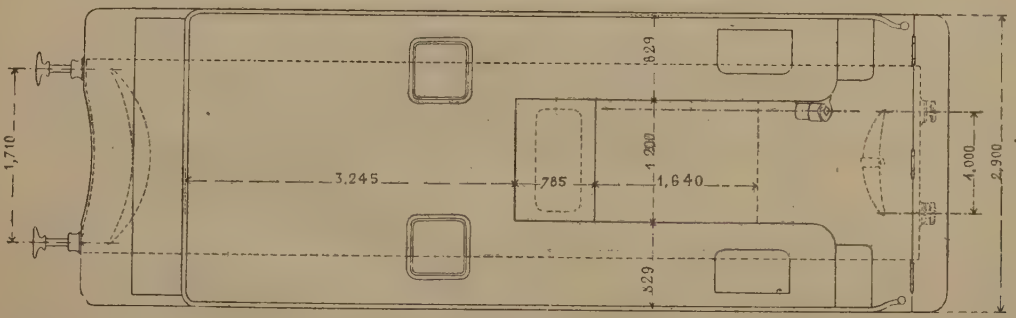


Fig. 65.

Figs. 64 to 66. — Group 3, γ, 1. — Tender of the 2 B (figs. 53 and 54), 2 B 1 (figs. 57 and 58) and 2 C (fig. 59 and 60) locomotives of the Paris-Lyons-Mediterranean Railway.

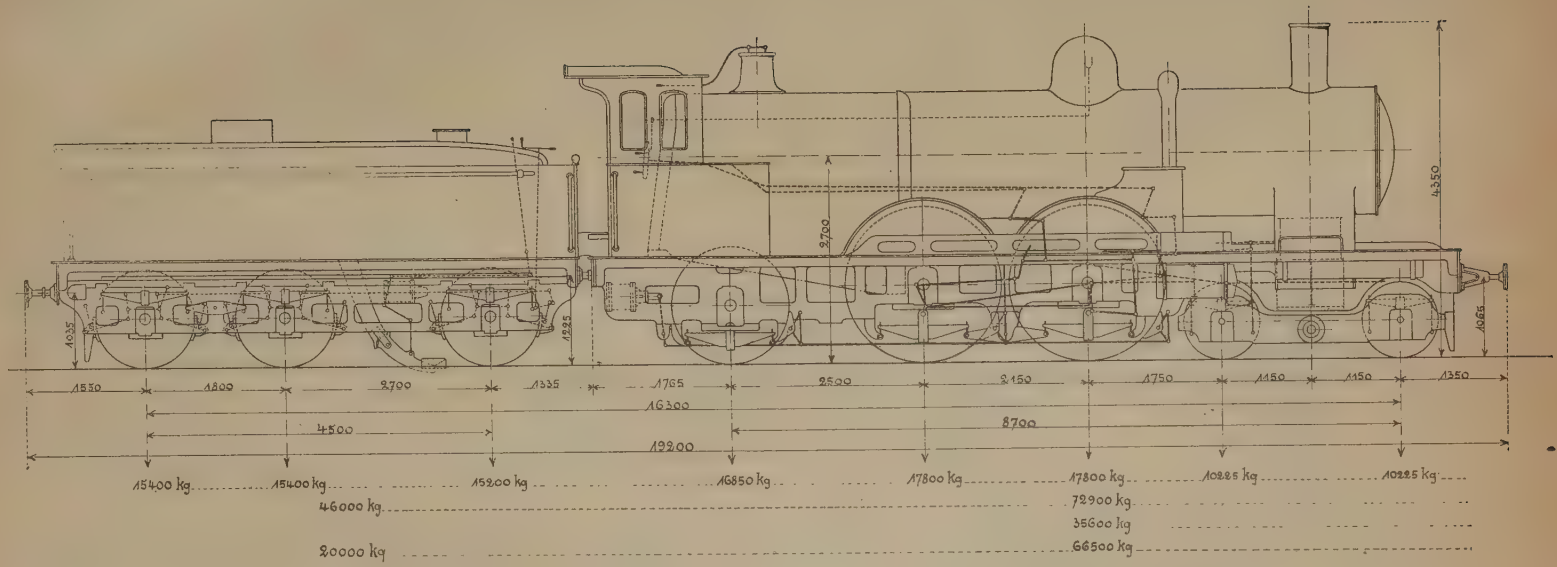


Fig. 67. — Group 3, γ, 2. — 2 B 1 Locomotive and tender of the French State Railway.

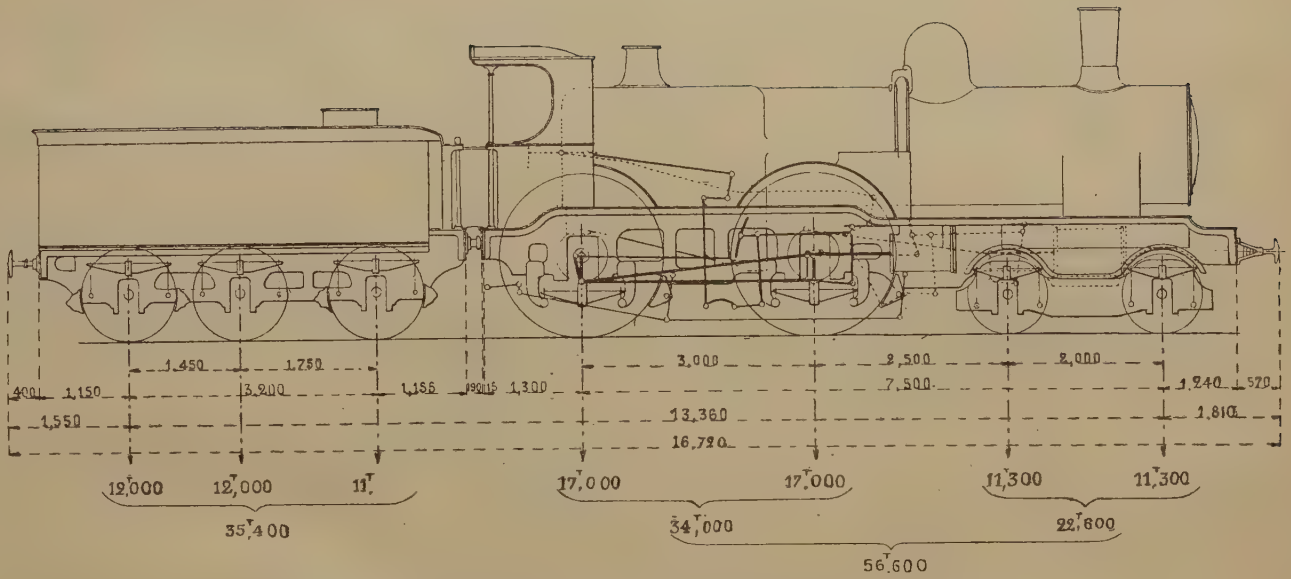


Fig. 68. — Group 3, 7, 3. — 2 B Locomotive of the Midi Railway.

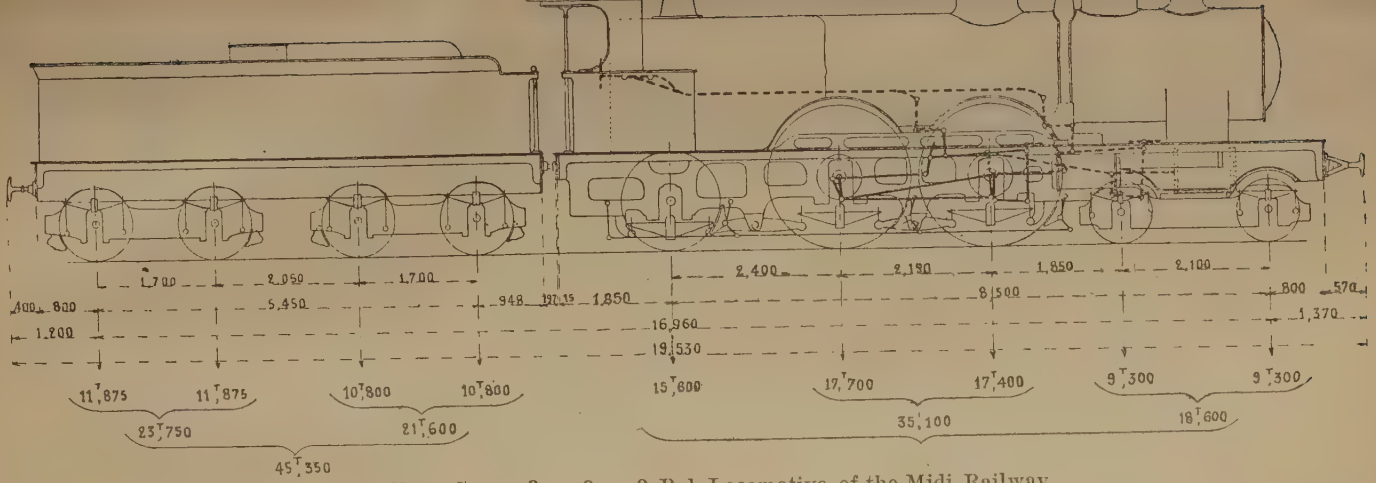


Fig. 69. — Group 3, γ, 3. — 2 B 1 Locomotive of the Midi Railway.

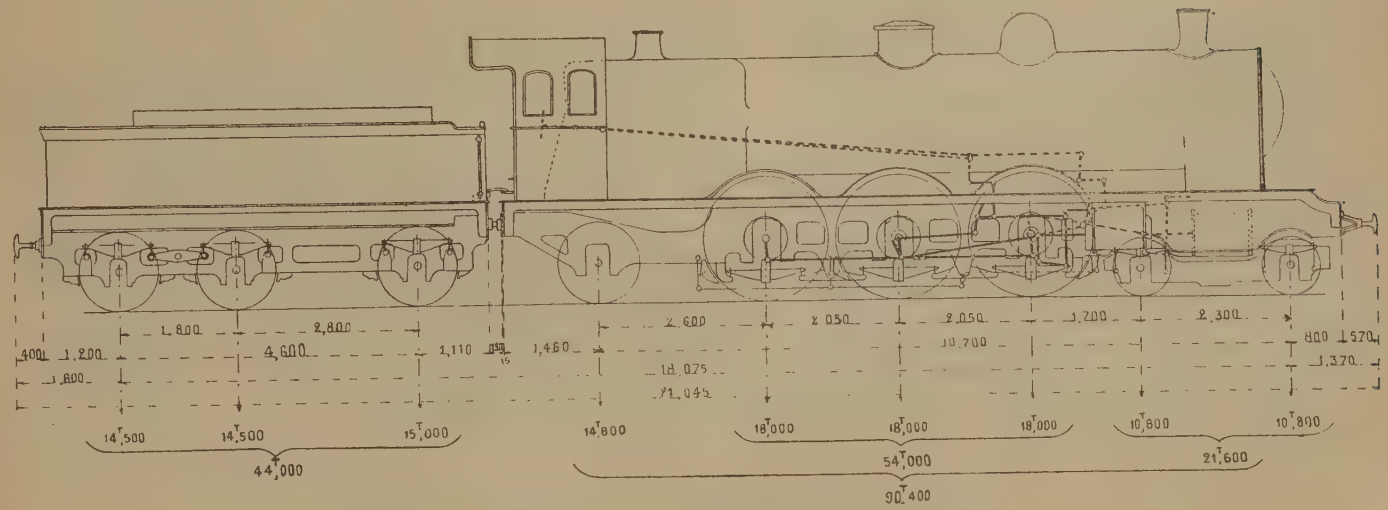


Fig. 70. — Group 3, γ, 3. — 2 C 1 Locomotive of the Midi Railway.

All these locomotives are of the de Glehn design, with four cylinders and double expansion. In the 2B and 2B1 types the whole of the fire-box is inside the frame; in the 2C1 the back of the fire-box is extended beyond the frame, so as to obtain a larger grate area. The fire-boxes are all flat topped; the barrels of the boilers are cylindrical. The driving axles of all three types are braked; in the case of the 2B1 type the trailing carrying axle is also braked.

The tenders of the 2B and 2C1 types have three axles; those of the 2B1 type have either three axles or four axles, with bogies with plate frames. All the tender axles are braked except in the case of type 2B, where the middle axle is not braked.

δ) **Great Britain.**

The Great Central Railway has a considerable number of locomotives of the types 2A1, 2B, 2B1 and 2C, which are able to run at speeds exceeding 100 kilometres (62 miles) per hour. Of these, there are in particular thirty-one locomotives of type 2B1, which have to be considered in this case, in so far as such speeds occur on this railway. These locomotives are represented in figure 71. They are three-cylinder compounds with grate inside the frame and the barrel of the boiler is cylindrical. The driving axles and the carrying trailing axle are braked. The tender has three axles.

c) **Locomotives of group 4.**

The chief dimensions of the locomotives belonging to this group are given in appendix 4.

α) **France.**

1. — *French Eastern Railway.*

The French Eastern Railway has fifty locomotives of type 2C for the trains running at speeds exceeding 100 kilometres (62 miles) per hour. They are, as shown in figures 72 and 73, four-cylinder compounds with de Glehn drive; the grate is inside the frame and slopes forward, the fire-box is flat-topped and the barrel of the boiler is cylindrical and fitted with two steam domes. Piston valves with spring rings are used. All the carrying and driving axles are braked, as well as all three axles of the tender, which is shown in figures 74 to 76.

2. — *French Northern Railway.*

This railway has nearly four hundred locomotives which can run or are intended to run at speeds exceeding 100 kilometres (62 miles) per hour; they are of types 2B, 2B1 and 2C. Each of these types includes several groups, which are distinguished by smaller or greater difference of design. The chief representatives of the different types are shown in figures 77 to 84. The older 2B locomotive, figures 77 and 78, has inside cylinders and flat slide valves, not balanced, and is a non-compound; it has a flat-topped fire-box, an inclined grate inside the frame and the barrel of the boiler is cylindrical. There are one hundred and three locomotives of this or of similar design. The driving axles alone are braked.

Of the three next types, the newer 2B (figs. 79 and 80), the 2B1 (fig. 81) and the 2C (figs. 82 to 84), there are fifty-six,

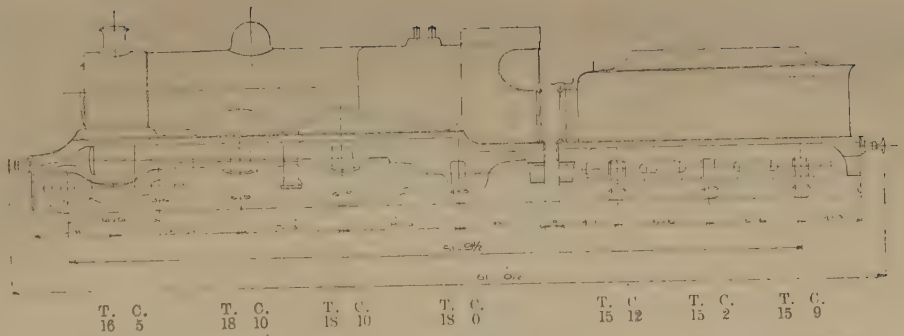


Fig. 71. — Group 3, δ. — 2 B 1 Locomotive of the Great Central Railway.

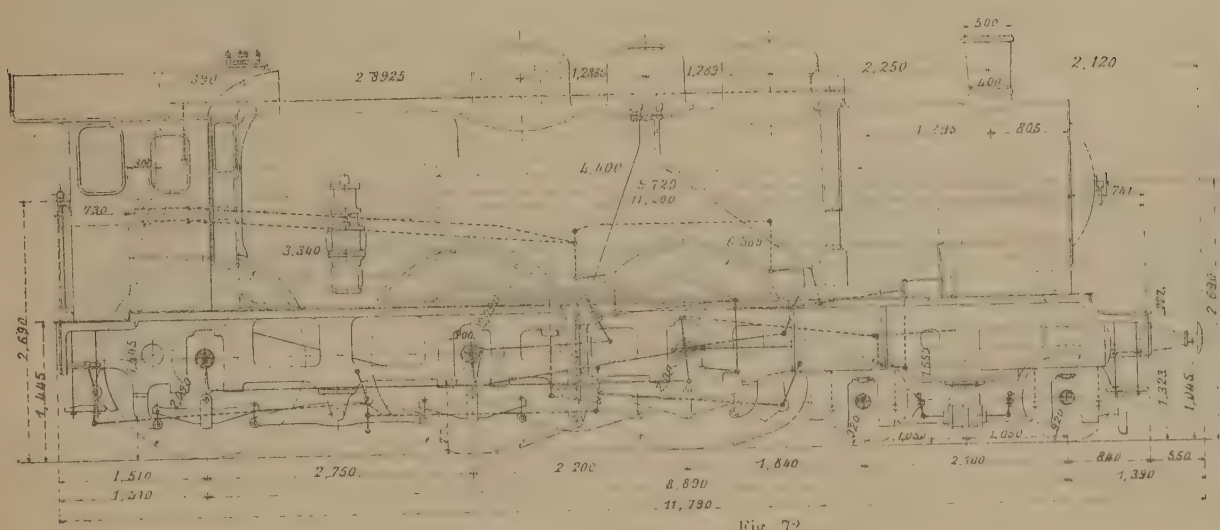
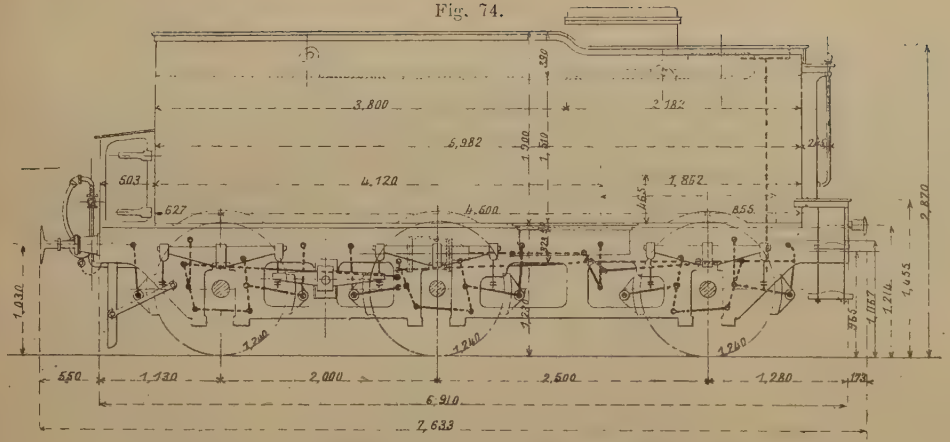


Fig. 72.

Fig. 73.

Figs. 72 and 73. — Group 4, α, 1. — 2 C Locomotive of the French Eastern Railway.

Fig. 74.



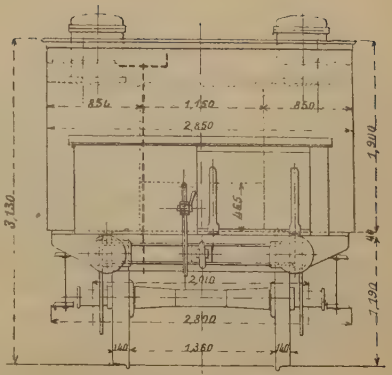


Fig. 76.

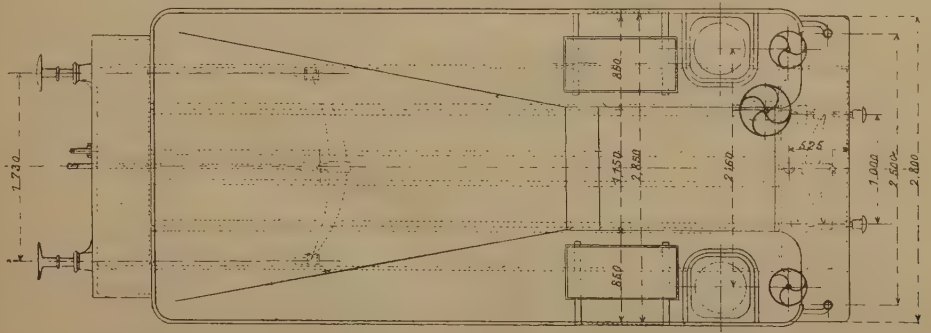
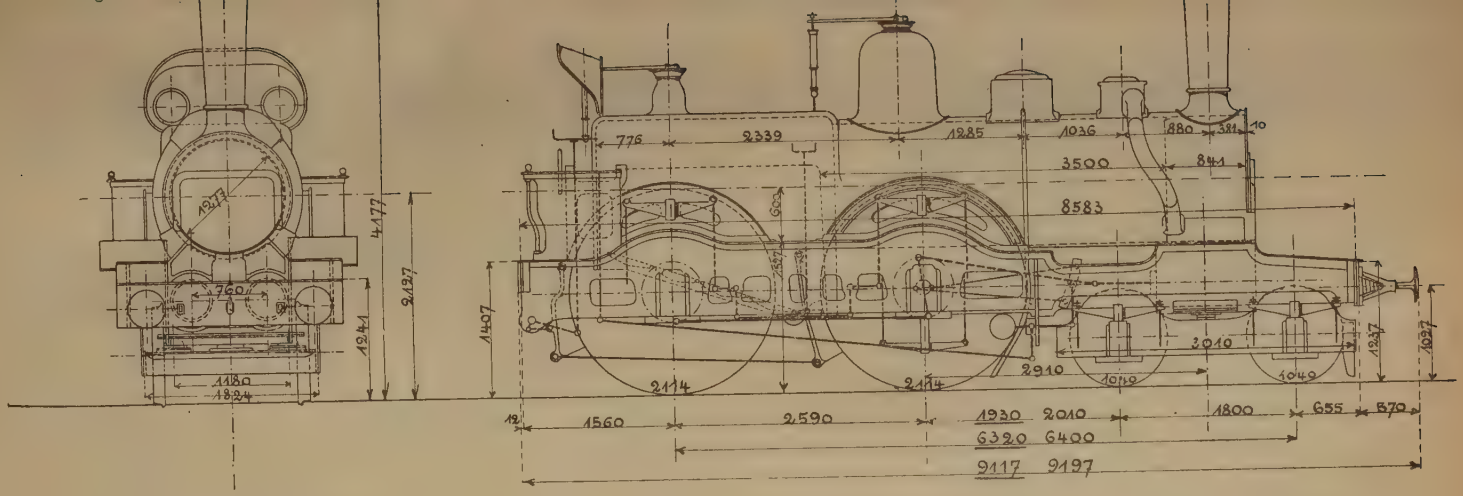


Fig. 75.

Figs. 74 to 76. — Group 4, *z*, 1. — Tender of the 2 C locomotive (figs. 72 and 73) of the French Eastern Railway.



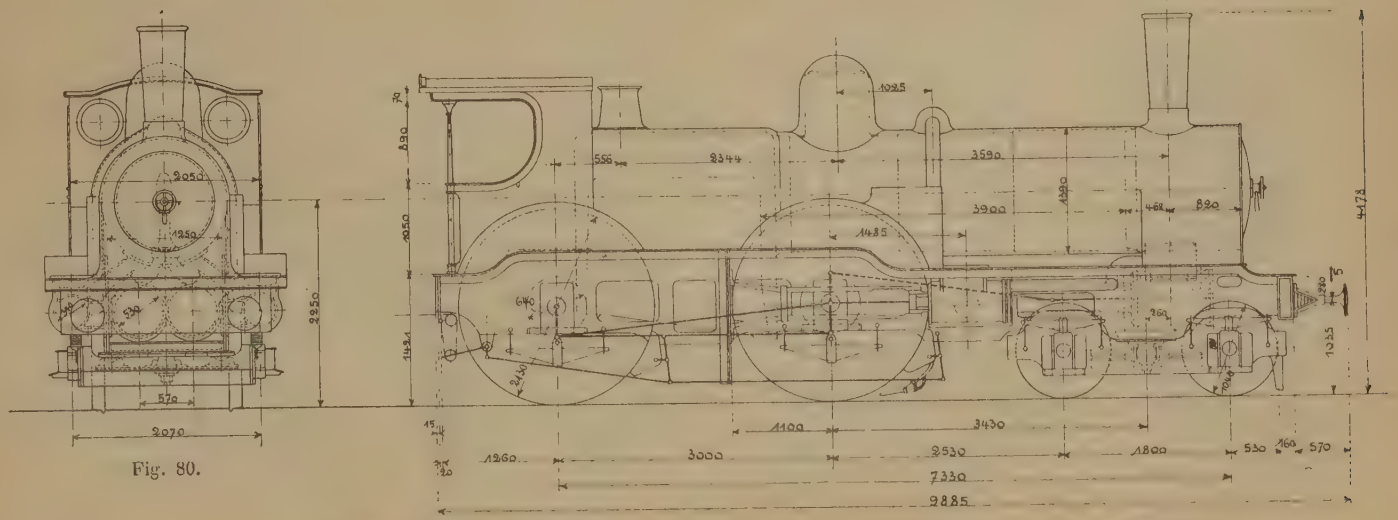


Fig. 80.

Fig. 79.

Figs. 77 to 80. — Group 4, α, 2. — 2 B Locomotives of the French Northern Railway.

thirty-five and twenty-five locomotives respectively. All these locomotives are double-expansion compounds, and have four cylinder and de Glehn separate drive. These locomotives also all have flat slide valves. These are balanced on type 2 B 1 (fig. 81) in the case of high pressure; on type 2 C (figs. 82 to 84) all the slide valves are balanced.

The fire-box, the grate and the boiler have the same shapes as on the older 2 B locomotives.

The bogie axles of the newer 2 B and of the 2 B 1 locomotives are not braked; the trailing carrying axles of the 2 B 1 locomotives are braked; all the axles of the 2 C locomotives are braked.

The tenders have three axles or four axles; all the axles are braked.

3. — *Orleans Railway.*

This administration also owns a considerable number of locomotives for high speeds, as follows :

1° Twenty-five locomotives of type 2 B (figs. 85 and 86);

2° Fourteen locomotives of type 2 B 1 (figs. 87 and 88);

3° Seventy locomotive of type 2 C (figs. 89 and 90);

4° Eighty-four locomotives of type 2 C 1 (figs. 91 and 92).

These locomotives illustrate very well how the 2 B type developed into the 2 C 1 type, while the main features were retained during every step of the development. These main features are : double expansion, four cylinders, high-pressure outside, low-pressure inside, de Glehn drive, acting on two axles, cylindrical barrel, flat-topped fire-box, inclined grate. In the 2 B, 2 B 1 and 2 C types the whole of the grate could still be accommodated inside the frame, but in the 2 C 1 type the back part had to be widened and extended beyond the frame so as to obtain the necessary grate area.

The bogie axles are not braked in the case of types 2 B, 2 B 1 and 2 C, but the driving axles are braked, and in the case of type 2 B 1 also the trailing carrying axle. In the case of type 2 C 1, on the other hand, the driving axles and the bogie axles are braked, but not the trailing carrying axle. The tenders have three axles, and all of them are braked.

β) **Great Britain.**

1. — *Caledonian Railway.*

The Caledonian Railway has sixty-two locomotives of type 2 B and seven locomotives of type 2 C, for speeds exceeding 100 kilometres (62 miles) per hour. The former can be divided into two groups which only exhibit minor differences. The designs are shown in figures 93 and 94.

Both types have two inside cylinders and are non-compounds; the fire-boxes are inside the frame. The tenders for type 2 B have either three or four axles; those for type 2 C all have four axles.

2. — *Great Eastern Railway.*

This railway, in order to haul the trains running at speeds exceeding 100 kilometres (62 miles) per hour, chiefly uses twin locomotives of the 2 B type; it owns one hundred and fifty-two such locomotives. A sketch of this locomotive is shown in

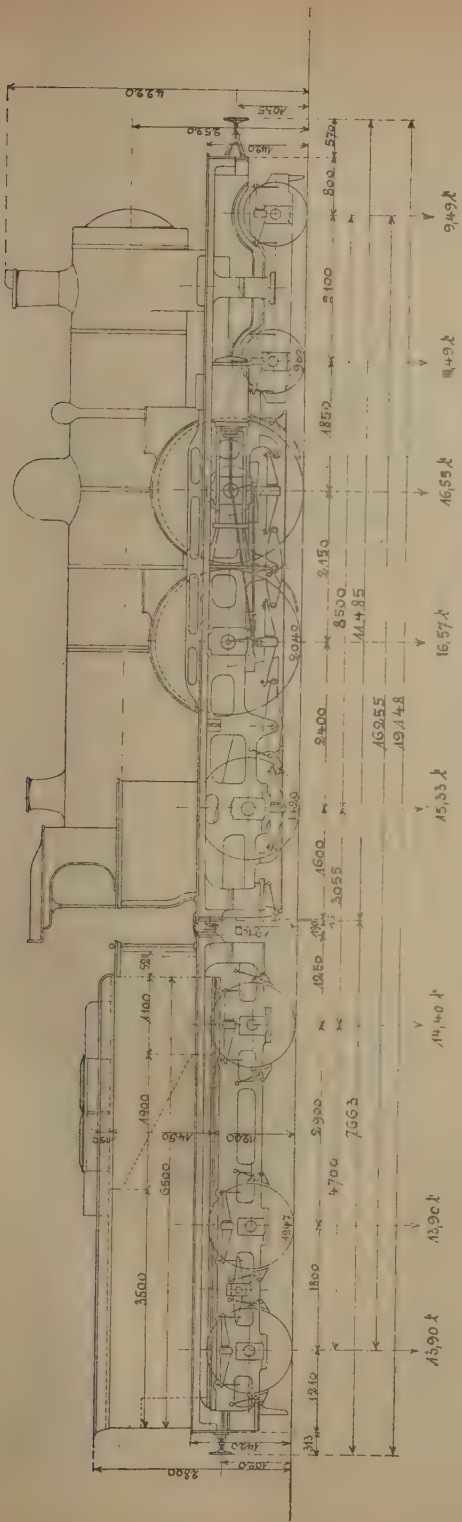


Fig. 81. — Group 4, α, 2. — 2 B 1 Locomotive of the French Northern Railway.

figure 95. The cylinders are inside and the flat slide valves are not balanced. The flat-topped fire-box is rather deep, and has an inclined grate which is inside the frame. The locomotives are equipped for auxiliary liquid-fuel firing. The tender has three axles.

3. — *Great Western Railway.*

Altogether there are nearly seven hundred locomotives on this railway, which can be used for hauling trains at speeds exceeding 100 kilometres (62 miles) per hour. There are six classes of tender locomotives, of the types 2A1, 1B, 2B, 2B1, 2C, and 2C1; in addition there are also two tank locomotives of the types 2B1 and 1C1. Figure 96 represents the 2B1 tank locomotive, and figure 97 the 2C tender locomotives.

The 2B1 tank locomotive is a non-compound with two cylinders; the back ring of the barrel is tapered. The 2C tender locomotive is a four-cylinder superheated-steam non-compound, with divided drive, acting on two axles.

Piston valves are used. The boiler has two taper rings and raised fire-box, but no steam dome. The three-axles tender is equipped with Ramsbottom scoop.

4. *Lancashire & Yorkshire Railway.*

This railway has sixty-nine locomotives of type 2B and forty locomotives of type 2B1 for speeds exceeding 100 kilometres (62 miles) per hour (see figs. 98 and 99). The locomotives are non-compounds and have two inside cylinders; the barrel of the boiler is cylindrical and has a small dome; the fire-box is flat-topped and the

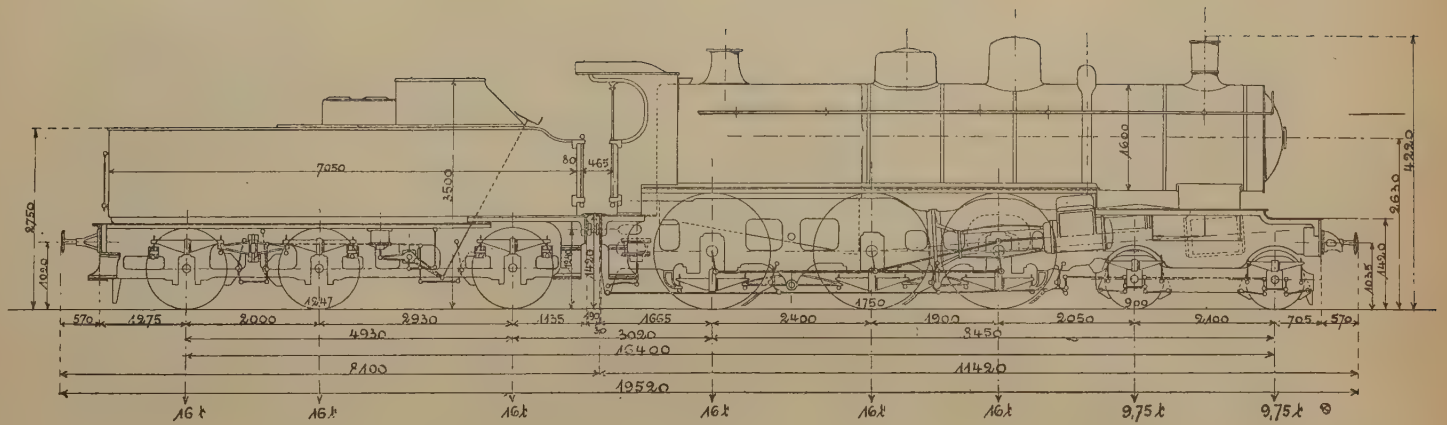


Fig. 82.

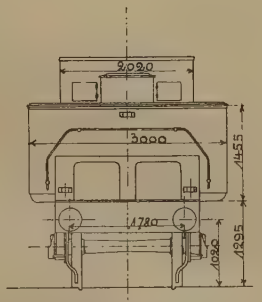


Fig. 84.

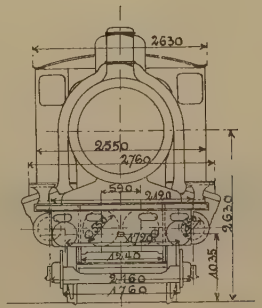


Fig. 83.

Figs. 82 to 84. — Group 4, α, 2. — 2 C Locomotive of the French Northern Railway.

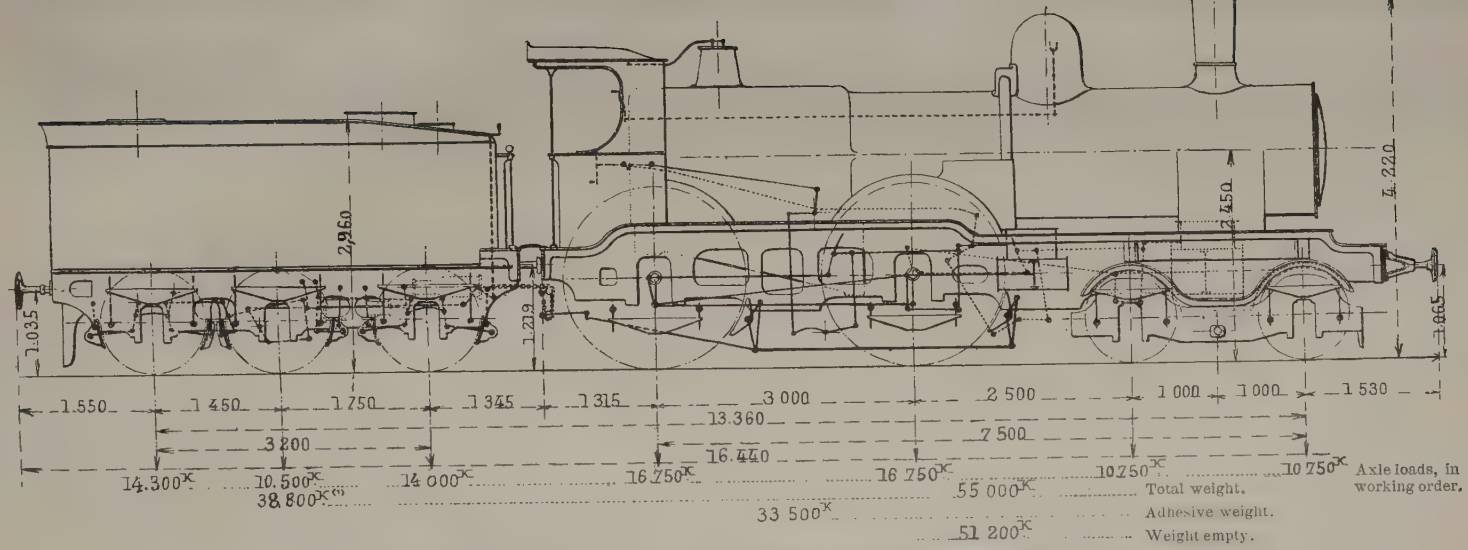


Fig. 85. — Group 4, α, 3. — 2 B locomotive of the Orleans Railway.

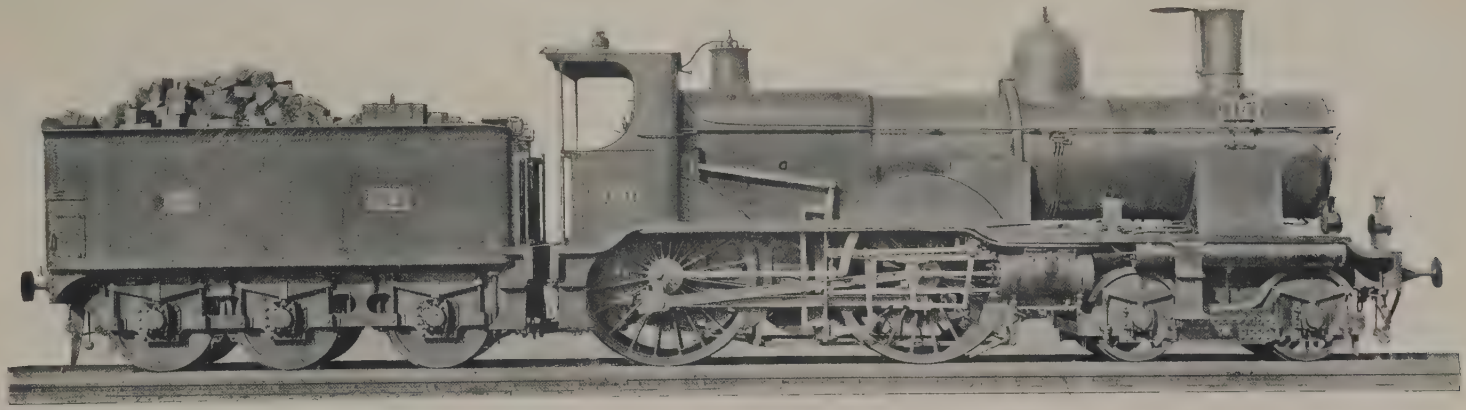


Fig. 86. — Group 4, α, 3. — 2 B locomotive of the Orleans Railway, represented in figure 85.

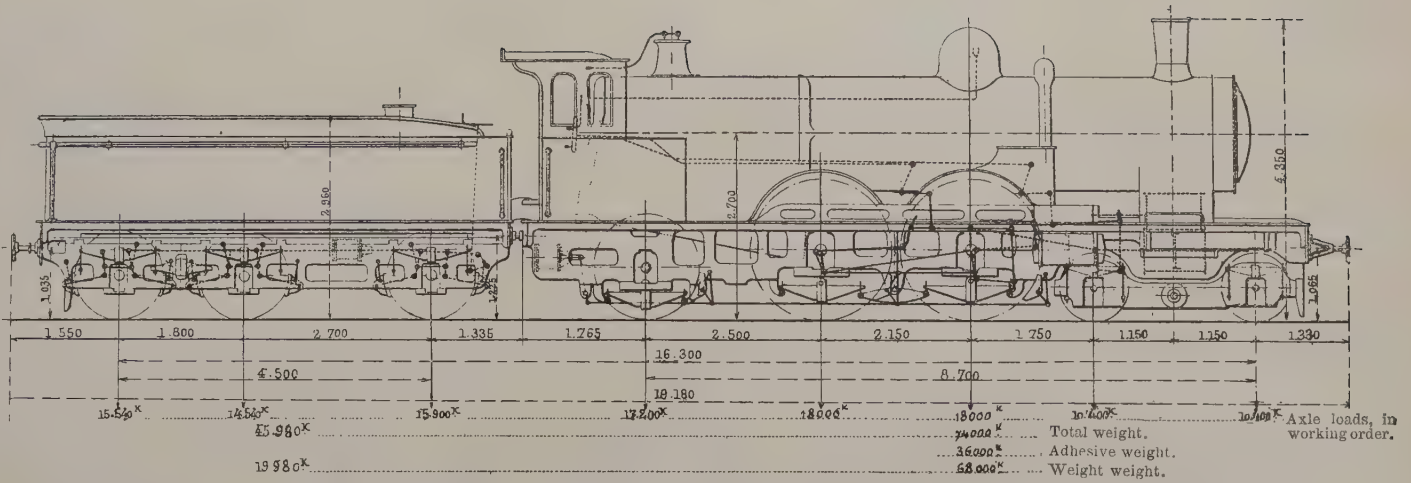


Fig. 87. — Group 4, α, 3. — 2 B 1 locomotive of the Orleans Railway.

Fig. 88. — Group 4, α, 3. — 2 B 1 locomotive of the Orleans Railway, represented in figure 87.

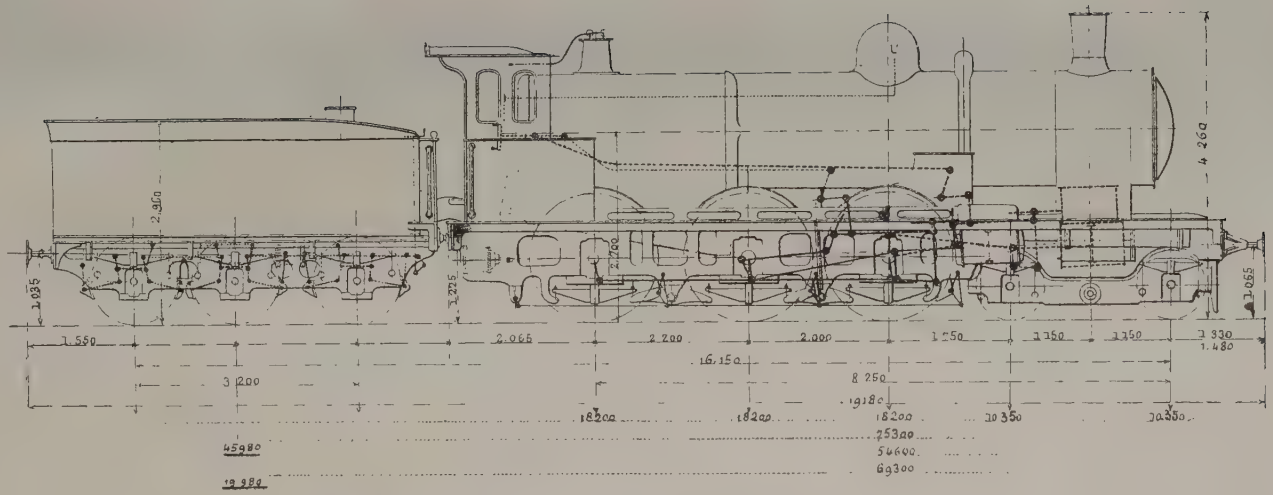


Fig. 89. — Group 4, α, 3. — 2 C locomotive of the Orleans Railway.

Fig. 90. — Group 4, α, 3. — 2 C locomotive of the Orleans Railway, represented in figure 89.

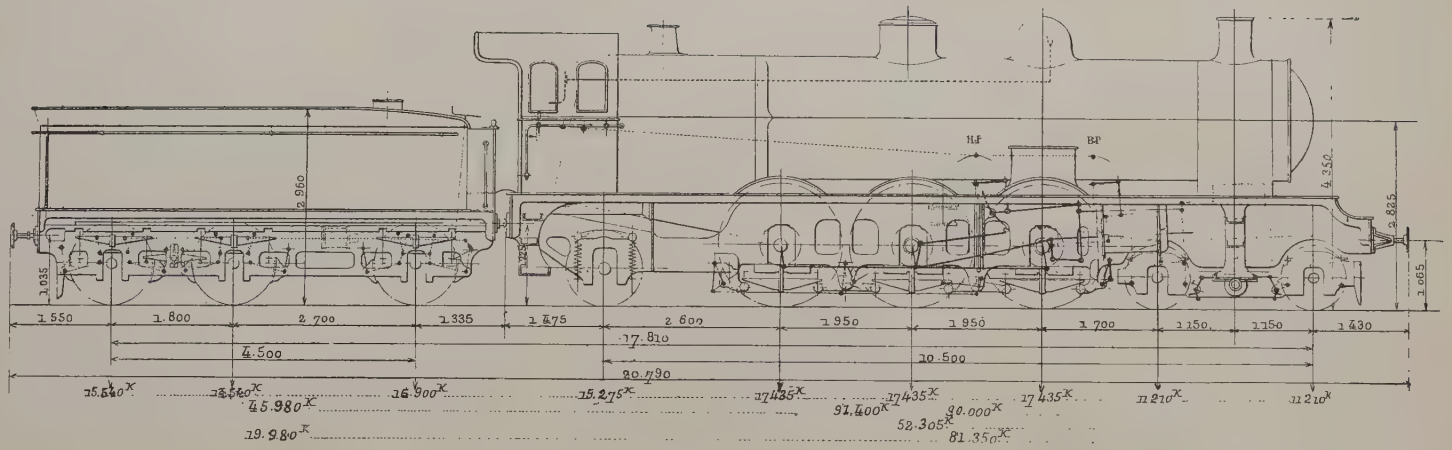


Fig. 91. — Group 4, α, 3. — 2 C 1 locomotive of the Orleans Railway.

Fig. 92. — Group 4, α, 3. — 2 C 1 locomotive of the Orleans Railway, represented in figure 91.

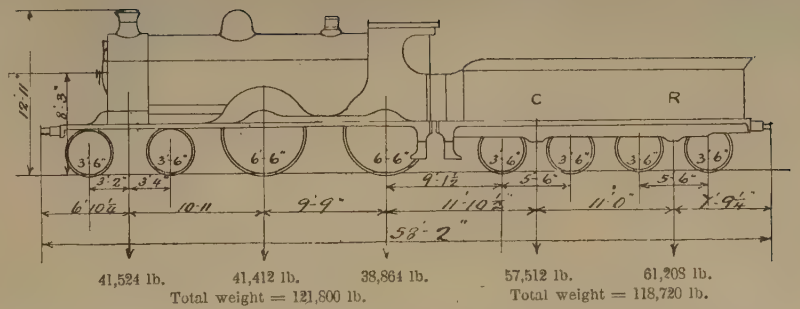


Fig. 93. — Group 4, β, 1. — 2 B locomotive of the Caledonian Railway.

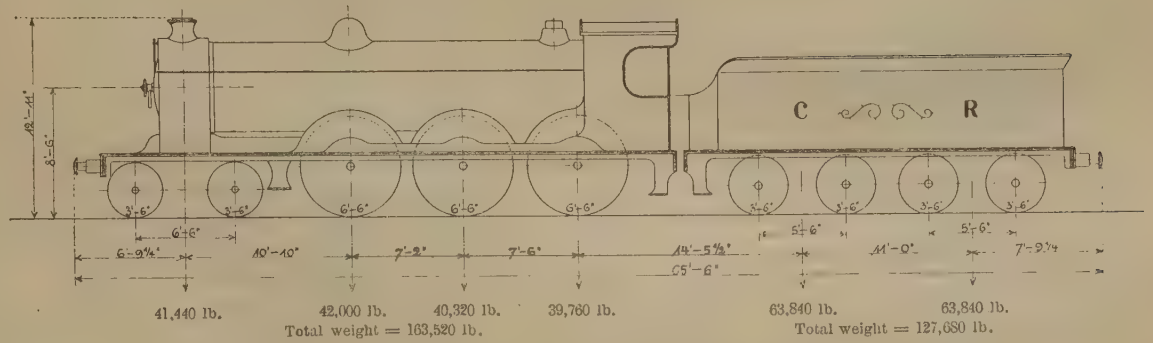
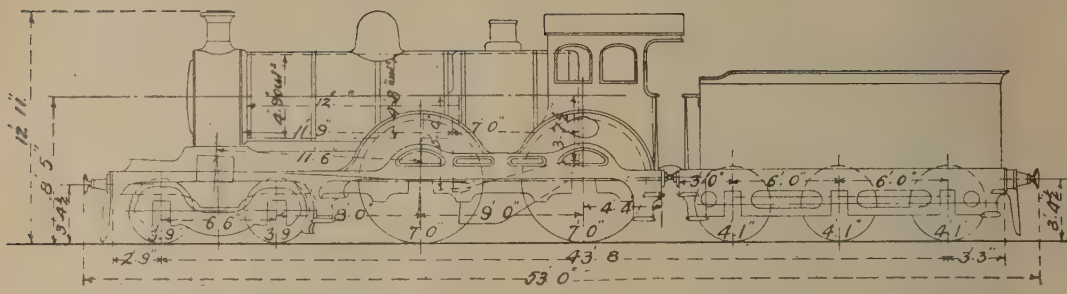


Fig. 94. — Group 4, β, 1. — 2 C locomotive of the Caledonian Railway.

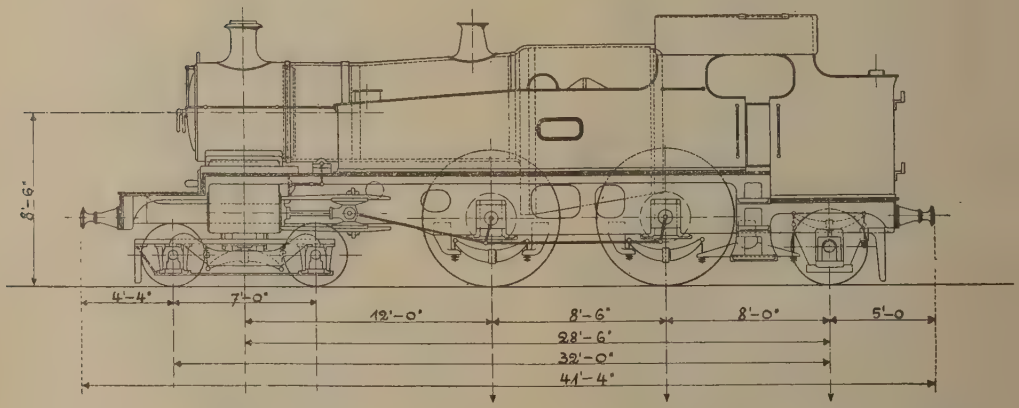


Weight, empty .	16 T. 0 C. 0 Q.	15 T. 14 C. 1 Q.	16 T. 2 C 1 Q.	6 T. 13 C. 2 Q.	6 T. 7 C. 3 Q.	6 T. 4 C. 3 Q.
Weight in working order. . . .	17 T. 5 C. 1 Q.	17 T. 9 C. 2 Q.	16 T. 19 C. 1 Q.	12 T. 2 C. 3 Q.	13 T. 3 C. 1 Q.	13 T. 19 C. 0 Q.

	T. C. Q.
Total weight, empty	47 16 2
— — in working order	51 14 0

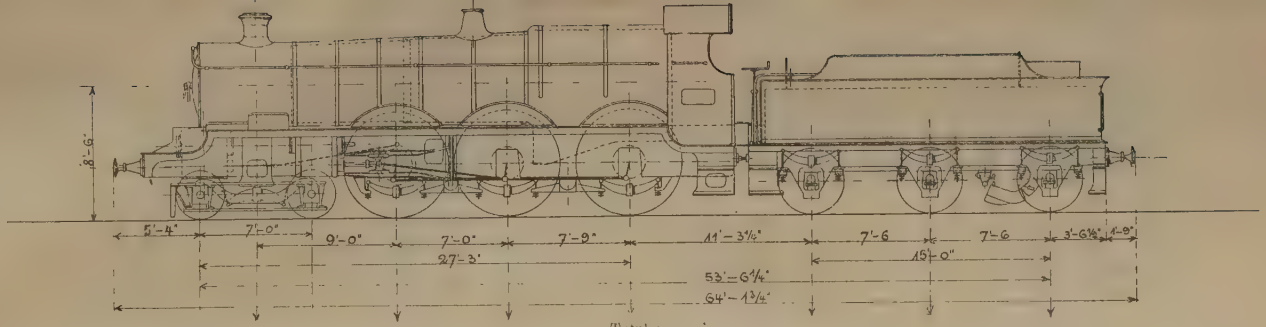
	T. C. Q.
Total weight, empty	19 6 0
— — in working order . . .	39 5 0

Fig. 95. — Group 4, ε, 2. — 2 B locomotive of the Great Eastern Railway.



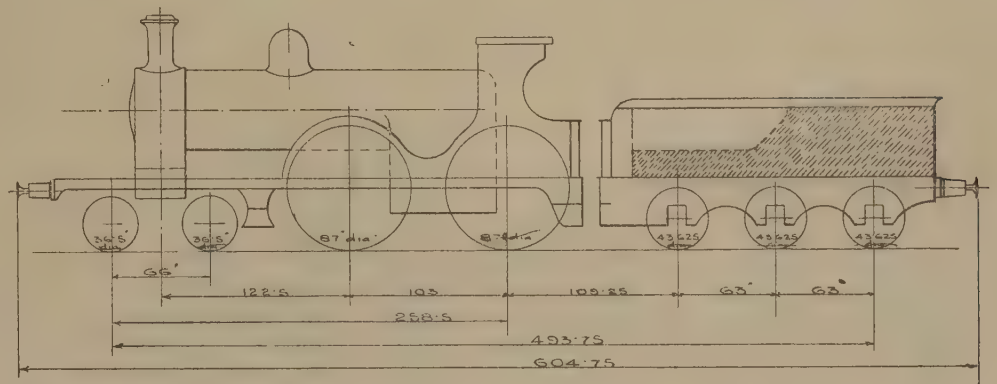
T. C.	T. C.	T. C.	T. C.	T. C.
22 0	19 0	18 0	16 0	75 0 full.
17 10	15 0	14 0	13 0	59 10 empty.

Fig. 96. — Group 4, β, 3. — 2 B 1 tank locomotive of the Great Western Railway.



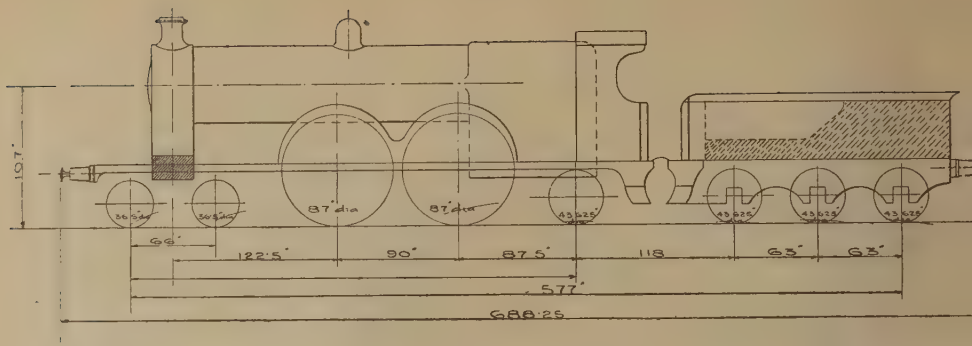
Total :							
20 T. 4 C.	18 T. 12 C.	18 T. 12 C.	18 T. 4 C.	75 T. 12 C.	13 T. 10 C.	13 T. 4 C.	13 T. 6 C. full.
18 T. 15 C.	17 T. 5 C.	17 T. 5 C.	16 T. 18 C.	70 T. 3 C.	6 T. 5 C.	6 T. 0 C.	6 T. 0 C. empty.

Fig. 97. — Group 4, β, 3. — 2 C locomotive of the Great Western Railway.



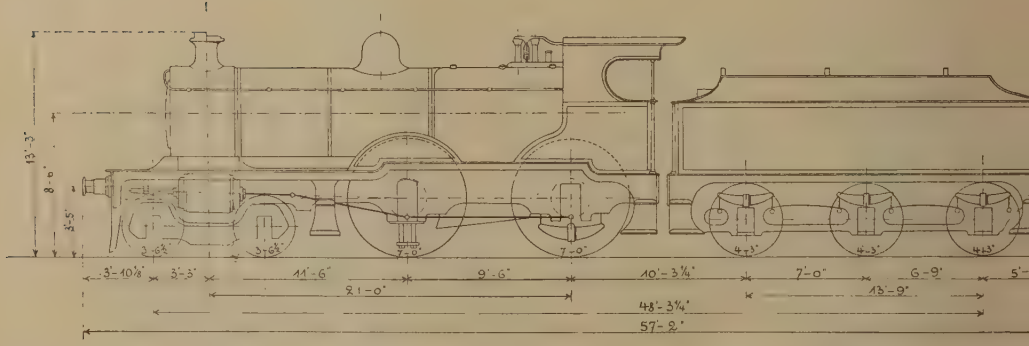
Weight, empty	12 T. 16 C. 0 Q.	14 T. 18 C. 3 Q.	13 T. 11 C. 1 Q.	5 T. 2 C. 0 Q.	5 T. 5 C. 0 Q. 4 T. 12 C. 3 Q.
Weight in working order	13 T. 16 C. 0 Q.	16 T. 10 C. 0 Q.	14 T. 10 C. 0 Q.	9 T. 0 C. 0 Q.	9 T. 0 C. 0 Q. 8 T. 2 C. 2 Q.

Fig. 98. — Group 4, β, 4. — 2 B locomotive of the Lancashire & Yorkshire Railway.



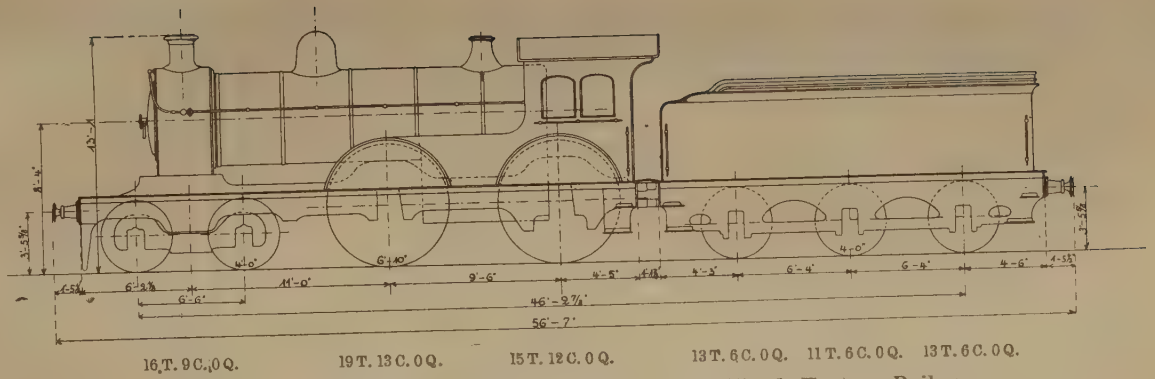
	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.	T. C. Q.
Weight, empty.	12 5 0	12 17 0	11 13 0	11 10 0	5 9 2	5 9 2	4 17 2
Weight in working order . .	14 7 1	17 10 0	17 10 0	13 19 0	10 10 1	10 10 1	9 12 3

Fig. 99. — Group 4, β, 4. — 2 B 1 locomotive of the Lancashire & Yorkshire Railway



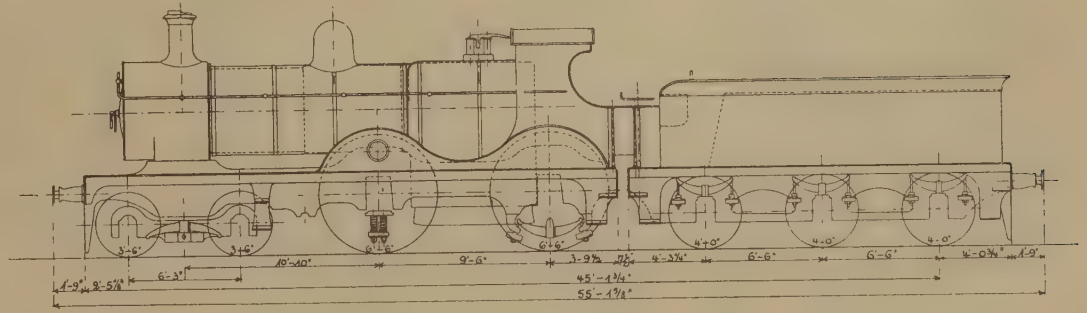
Weight, empty .	19 T. 3 C. 1 Q.	18 T. 5 C. 0 Q.	18 T. 0 C. 0 Q.	8 T. 13 C. 2 Q.	7 T. 4 C. 2 Q.	7 T. 8 C. 0 Q
Weight in working order . .	20 T. 14 C. 0 Q.	19 T. 15 C. 0 Q.	19 T. 7 C. 0 Q.	14 T. 14 C. 0 Q.	13 T. 18 C. 0 Q.	14 T. 6 C. 2 Q

Fig. 100. — Group 4, β, 5. — 2 B locomotive of the Midland Railway.



16 T. 9 C. 0 Q. 19 T. 13 C. 0 Q. 15 T. 12 C. 0 Q. 13 T. 6 C. 0 Q. 11 T. 6 C. 0 Q. 13 T. 6 C. 0 Q.

Fig. 101. — Group 4, β, 6. — 2 B locomotive of the North Eastern Railway.



Weight in working order . . 17 T. 7 C. 17 T. 12 C. 17 T. 6 C. 12 T. 10 C. 13 T. 0 C. 13 T. 12 C.

34 T. 18 C.

Fig. 102. — Group 4, β, 7. — 2 B locomotive of the South Eastern & Chatham Railway.

grate is horizontal. The tenders have three axles.

5. — *Midland Railway.*

There are two classes of locomotives for speeds exceeding 100 kilometres (62 miles) per hour, of the 2 B type; there are eighty two-cylinder non-compound and thirty-five three-cylinder compounds. Figure 100 represents a sketch of the latter.

The high-pressure cylinder is inside, the two low-pressure cylinders are outside; all three cylinders act on the first driving axle. The tenders have three or four axles.

6. — *North Eastern Railway.*

This railway owns sixty locomotives of type 2 B (see fig. 101), which are used for trains having speeds of over 100 kilometres (62 miles) per hour. The locomotive are non-compounds with two inside cylinders and piston valves. The tender has three axles.

7. — *South Eastern & Chatham Railway.*

There are two classes of type 2 B, of which there are fifty-one and sixteen locomotives respectively (total, sixty-seven); these only differ slightly in their chief dimensions and the heaviest is shown in figure 102. They are twin locomotives with inside cylinders, and have slide flat valves, not balanced. The tenders have three axles.

III. — Speeds and particulars of the lines.

a) Group 3.

The answers received from railways belonging the group 3 (railways which only exceptionally have speeds exceeding 100 kilometres (62 miles) per hour) contain the following items of interest :

Speeds of up to 110 kilometres (68·4 miles) per hour are attained on the Belgian State Railway, particularly if a train is late; this occurs on sections with down gradients of 5 per mil, or even up to 6 per mil if the slope is short, and on curves with a radius of 900 metres (45 chains and upwards. Such speeds are) not attained on up gradients which are at all worth mentioning.

Figure 103 represents an instance of such a Belgian line, which gradually descends, and where trains run down with speeds of up to 110 kilometres (68·4 miles) per hour; it is a section of the line between Tirlemont and Bleyberg on the German frontier. Figure 104 represents a section of the Ghent-Ostend line, which on the whole is nearly level; it is an instance of a Belgian line on which trains run in both directions at speeds exceeding 100 kilometres (62 miles) per hour.

Speeds of over 100 kilometres (62 miles) per hour, up to 110 kilometres (68·4 miles) per hour, are also attained on the Baden State Railway, as a rule only on level or slightly-inclined lines, in cases of lateness. The steepest gradients on which such speeds may be attained must not exceed 4·33 per mil and the sharpest curve must not have a radius of less than 1,100 metres (55 chains); these figures are fixed by law for the whole of Germany as far as the regular service is concerned. During trial runs made with the 2 B 1 locomotive represented in figures 37 to 40, speeds of up to 145 kilometres (90·1 miles) per hour were obtained with a trial train of 16 axles.

On the Paris-Lyons-Mediterranean Railway the maximum speed, exceptionally

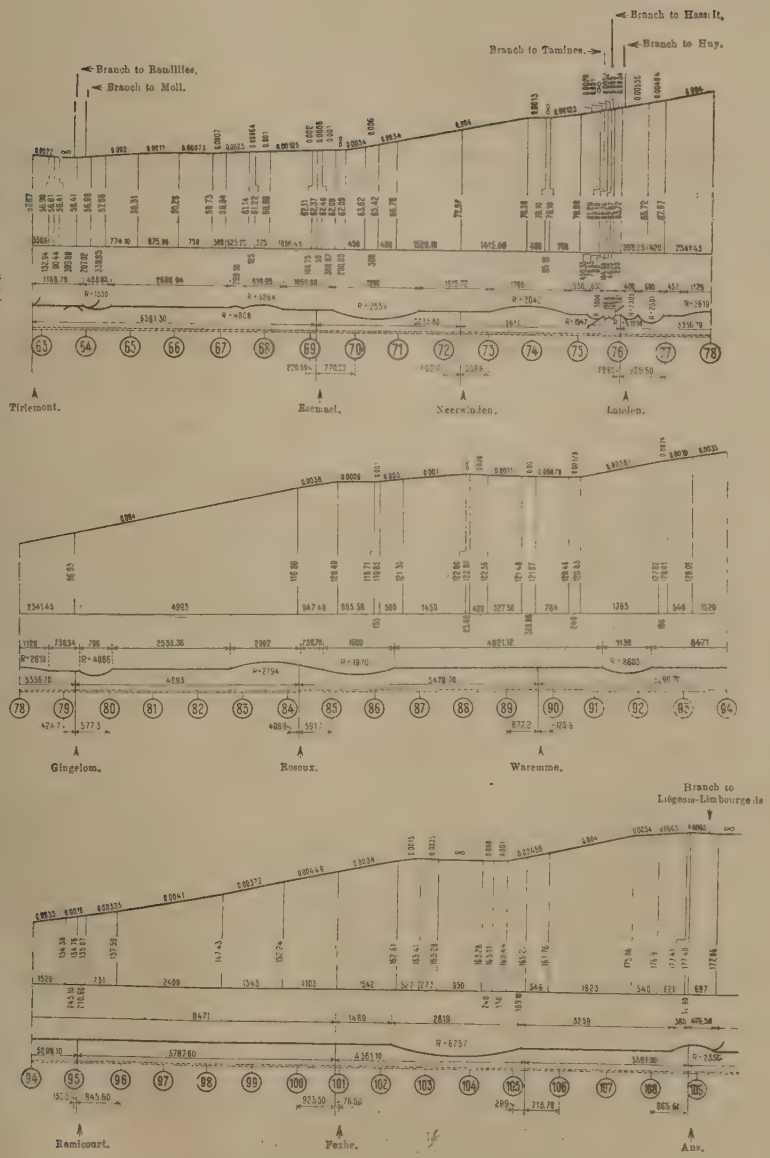


Fig. 103. — Group 3, α. — Profile of the Tirlemont-Ans section of the Belgian State Railway.

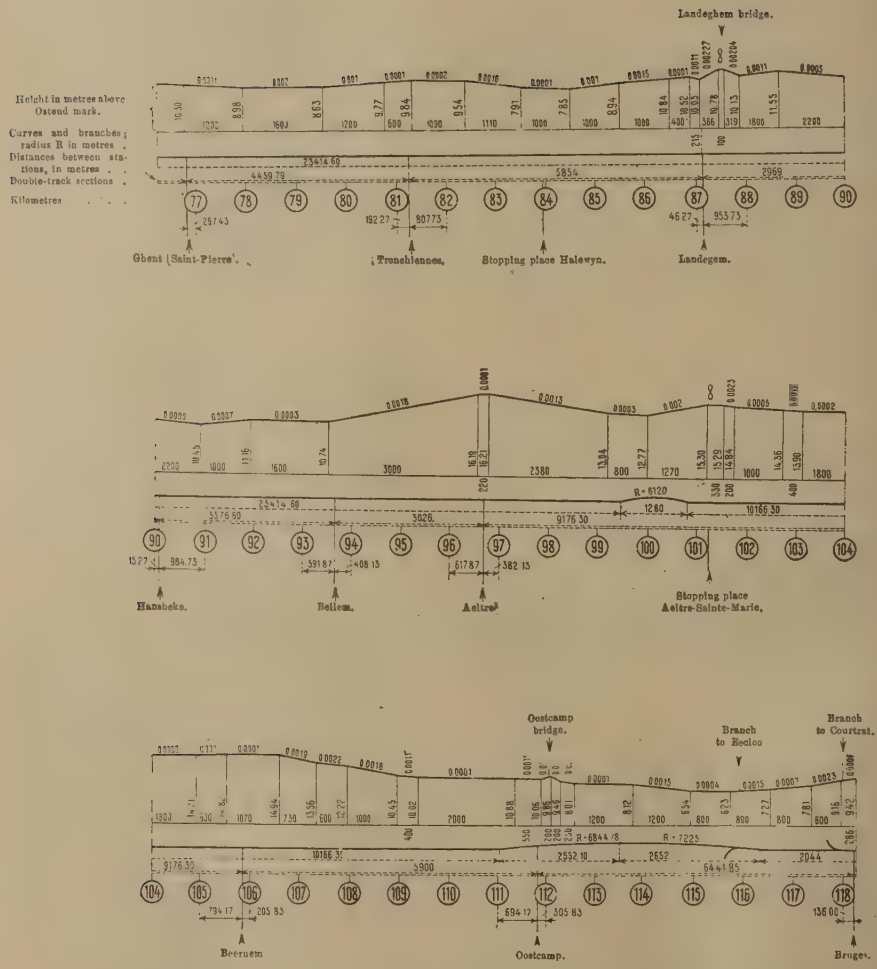


Fig. 104. — Group 3, α. — Profile of the Ghent (Saint-Pierre)-Bruges section of the Belgian State Railway.

attained, is 115 kilometres (71·5 miles) per hour; on the French State Railway it is 110 kilometres (68·4 miles) per hour.

The Midi Railway runs its South Express over the Bordeaux-Irun lines at a speed of up to 112 kilometres (69·6 miles) per hour, on sections where the line is level or has down gradients not exceeding 5 per mil, and curves with a radius of not less 700 metres (35 chains). A section of line, having an up gradient of 4 per mil, about 1 kilometre (0·62 mile) long, is taken at the same speed, evidently with a rush.

b) **Group 4.**

Among the information supplied by the railways belonging to group 4 (railways which in regular working have trains with speeds exceeding 100 kilometres [62 miles] per hour), we have in the first place to note that supplied by the French Northern Railway. Trains having higher speeds than that named run in particular on the three lines Paris-Calais, Paris-Belgian frontier—Charleroi, and Paris-Lille.

The profiles of these three lines are reproduced in figures 105 to 107. The sections on which speeds exceeding 100 kilometres (62 miles) per hour are attained are marked on figures 105 and 106 by a thick horizontal line under the corresponding part of the profile and by underlining the names of the end stations of these sections. On the line shown in figure 107, speeds exceeding 100 kilometres (62 miles) per hour are attained on all sections between any two stopping points. The stopping points are underlined on this figure. Speeds exceeding 100 kilometres (62 miles) per hour, and up to the admissible maximum of 120 kilometres (74·5 miles) per hour, are attained on the sections shown in figures 105 to 107, when running down gradients not steeper than 5 per mil, when running on the flat and when running up gradients not steeper than 3 per mil, and on curves having a radius of at least 500 metres (25 chains).

On the French Eastern Railway and on the Orleans Railway, speeds of up to 120 kilometres (74·5 miles) per hour are attained under similar conditions. In this case also the smallest radius of any curve considered is 500 metres (25 chains).

On the English lines also, the speeds reported exceed 100 kilometres (62 miles) per hour quite appreciably.

The Caledonian Railway, the Great Eastern Railway and the South Eastern and Chatham Railway all give 70 miles per hour as their maximum speed. On the North Eastern Railway, speeds of 72 to 75 miles per hour are attained; the steepest up and down gradients on which such speeds are attained are 2·8 per mil (1 in 356), and the sharpest curves have a radius of 403 metres (20 chains). The Midland Railway states that speeds exceeding 60 miles per hour are not attained on up gradients, but that speeds exceeding 62 miles per hour (it is not stated how much faster) are attained on down gradients of up to 6·25 per mil.

The Lancashire and Yorkshire Railway reports maximum speeds of 76·74 miles per hour, and the Great Western Railway of 80 miles per hour.

IV. — Performance of the locomotives.

As not only the speed, but also the maximum power of the locomotives is of

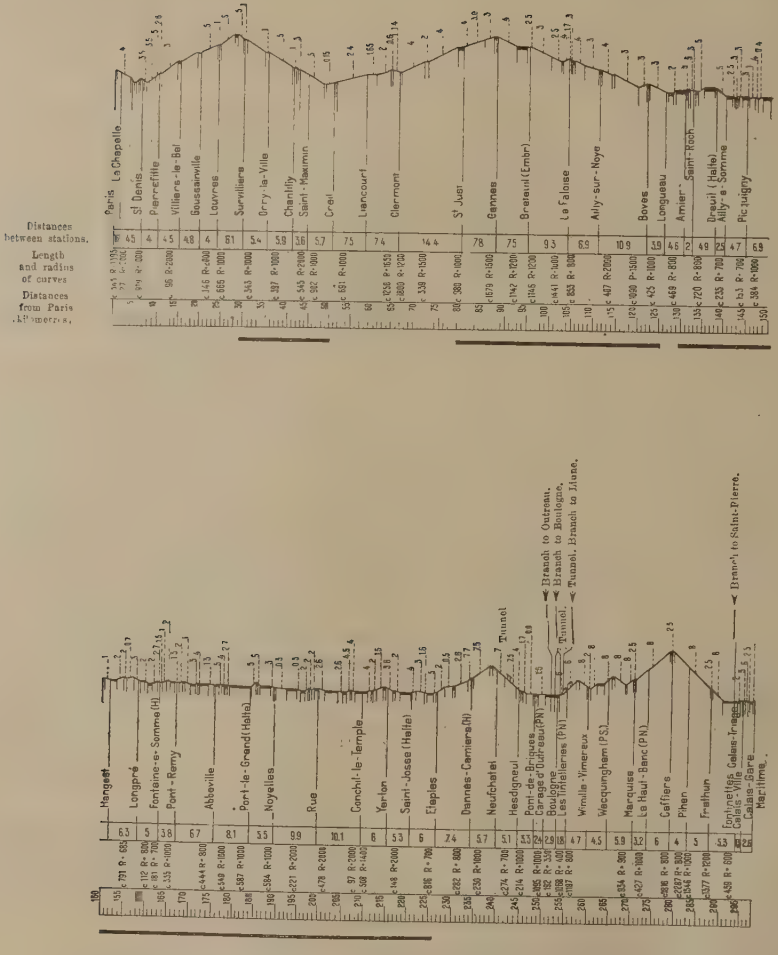


Fig. 105. — Group 4, *a*, 2. — Profile of the Paris-Calais line, French Northern Railway.

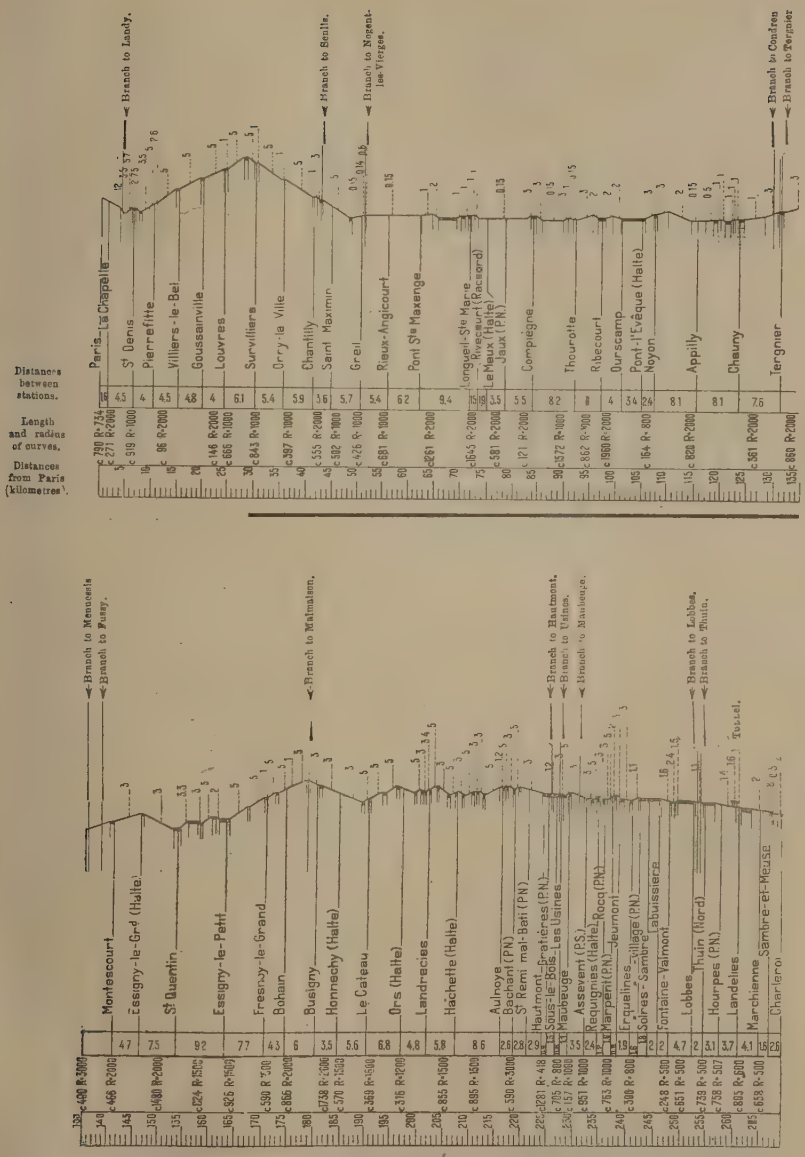


Fig. 106. — Group 4, α, 2. — Profile of the Paris-Charleroi line, French Northern Railway.

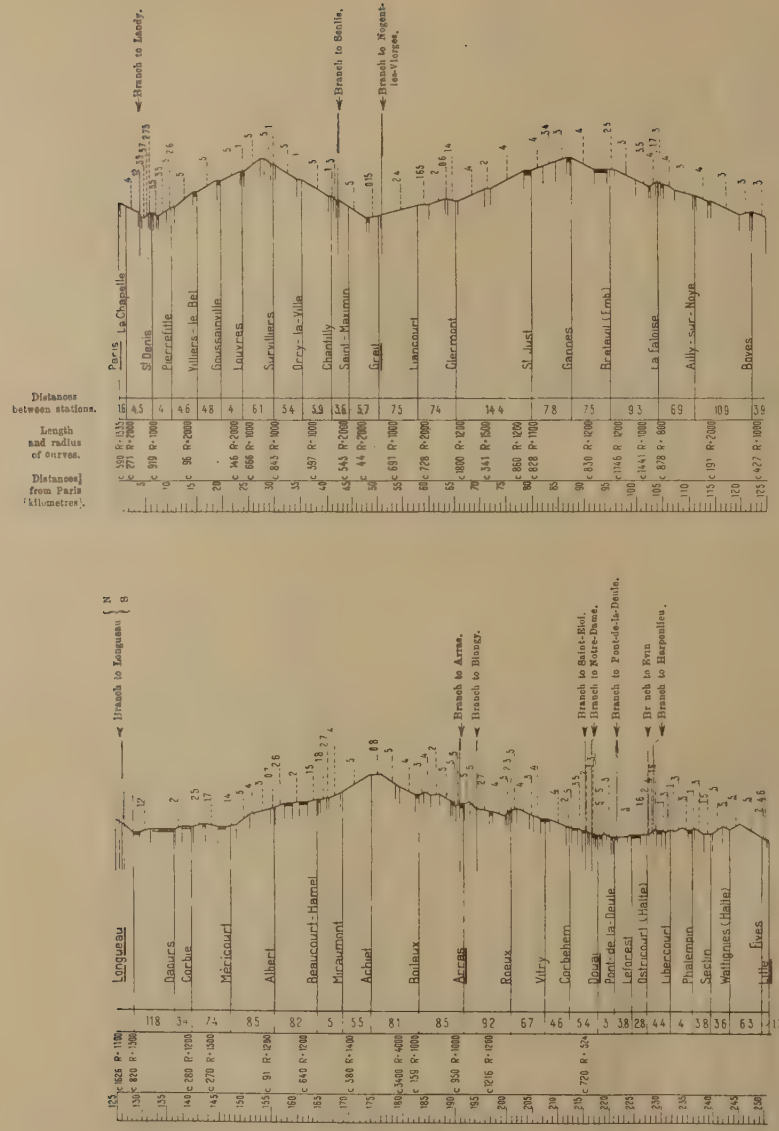


Fig. 107. — Group 4, α, 2. — Profile of the Paris-Lille line, French Northern Railway.

interest, it seems advisable to extend the enquiry to this point, in order to ascertain, what longest runs of this kind are made either without stopping, or without change of locomotive. It will perhaps be also of interest to know what the average annual work done by such locomotives is. A summary of the answers received is given in appendix 5.

In the first place, as regards the longest runs without stops, these amount to from 100 to 200 kilometres (62 to 124 miles) on half of the railways in question (eight); one quarter (four) gives runs of from 200 to 300 kilometres (124 to 186 miles); and one eighth (two) gives runs of less than 100 kilometres (62 miles), and another eighth (two), of over 300 kilometres (186 miles). The longest run made without a stop is reported by the Great Western Railway, namely Paddington-Plymouth, 226·5 miles; next comes the Midland Railway with 207 miles.

The longest runs made without change of locomotive, either are the same as the longest non-stop runs, or are in some cases considerably greater.

The first place is again occupied by the Great Western Railway, which reports Paddington to Weymouth return, 309 miles. Next comes the Orleans Railway with the St. Pierre-de-Corps (Tours)-Bordeaux run, 347 kilometres (216 miles); a short time ago the French Northern Railway had its "North Express" on the Paris-Liége line hauled a distance of 370 kilometres (230 miles) without change of locomotive.

These great individual performance also correspond as a rule to the average distances run by a locomotive, as is shown in columns 7, 8 and 9 of appendix 5. Unfortunately the figures given in the last column are not strictly comparable, because the average answers do not always definitely state whether the figures include the locomotives in steam or the locomotives under repair, of the same class. Particulars, as far as available, are given in column 10 of appendix 5.

Attention may however be drawn, as particularly noteworthy, to the average annual mileage exceeding 100,000 kilometres (62,000 miles), of locomotives on some lines, as for instance on the Baden State Railway, the Orleans Railway and the Caledonian Railway.

The average annual mileage of the Baden 2 B 1 locomotives, 113,985 kilometres (70,828 miles), and that of the Orleans Railway, 101,000 kilometres (62,760 miles), both refer to the whole class of the locomotives in question, including those under repair and the reserves kept ready in order to ensure the proper carrying out of the service, The figure given by the Caledonian Railway is 78,627 miles, but it is not stated what this figure includes.

Finally, some particulars about the maximum annual mileage of individual locomotives are of interest. Such figures are given by the Baden State Railway, namely 174,022 kilometres (108,134 miles) and by the French Northern Railway, namely 112,500 kilometres (69,900 miles); these locomotives, in both cases, are of the 2 B 1 type.

V. — Composition of the trains

Although the design and the composition of the trains hauled at speeds exceeding 100 kilometres (62 miles) per hour are

not directly related to the chief question which we are considering, we think we should at least touch upon the subject. In addition to the weight and the number of axles of the trains hauled at speeds exceeding 100 kilometres (62 miles) per hour, special interest attaches to the composition of these trains as regards the number of the carriages and the number of axles of the individual carriages.

Appendix 6 contains a summary of the answers received. They show that the total number of axles of the carriages of these trains varies within rather wide limits, namely between 20 and 60 axles, and the total weight of the carriages accordingly also varies, between 120 and 400 tons. The greatest numbers of axles are reported by the Great Central Railway and the Great Eastern Railway. If we compare the train weights, we find the highest figures, about 400 tons, on the Great Eastern Railway, the Great Western Railway and the Orleans Railway. The French Eastern Railway approaches this figure very closely, with 374 tons. Otherwise the figures are very variable; weights of over 300 tons occur in a few cases, and weights of over 200 tons are frequent; particulars are given in column 6 of appendix 6. As regards the composition of the trains, bogie carriages predominate, and four axles are much more usual than six. Flexible gangway connections (" concertina " connexions) are used nearly everywhere. On the other hand however, carriages with two and with three axles are also to be found in these fast trains, and not only by themselves, forming complete trains, but also mixed four-axled and six-axled bogie carriages. Some very detailed information sent by the Midland Railway is of particular interest in this respect : a train running on that line at speeds exceeding 100 kilometres (62 miles) per hour consists of 26 axles, and is made up of one two-axled, one six-axled, three four-axled and two three-axled carriages (see appendix 6). The French State Railway has trains consisting of two-axled carriages together with a four-axled dining car; on the Belgian State Railway a bogie saloon carriage is run regularly in the middle of trains made up of three-axled carriages. The weights of the carriages, particulars of which are given in columns 8 to 11, appendix 6, show that these two-axled and three-axled carriages, with few exceptions, are not so very much lighter than the lighter four-axled carriages, and that consequently large carriages with a wheelbase of corresponding length are in question.

VI. — Particulars of the locomotives.

Some of those particulars which are of special importance in the case of high-speed locomotives, will be considered in the following section.

a) Valve gear

α) Flat slide valves.

In this respect, it is to be noted that in spite of the great number of revolutions per unit of time which the driving wheels of the locomotives can attain at the speeds we are considering (see below, under *c*), the flat slide valve still maintains its position. It is still used in its simplest form, not balanced, on some of the French and English locomotives which have been re-

ferred to, for instance on the 1 B and 2 B locomotives of the Paris-Lyons-Mediterranean Railway; on the low-pressure cylinders of the 2 B 1 locomotives of the French State Railway while the high-pressure cylinders of these locomotives also have flat slide valves, but balanced (see below); on the French Northern Railway (2 B locomotive); and on the Midi Railway (2 B and 2 B 1 locomotives, and low-pressure cylinders of the 2 C 1 locomotive). The non-balanced flat slide valve is also to be found in England, on the Great Central Railway, the Great Eastern Railway, the Midland Railway, the Lancashire and Yorkshire Railway, and the South Eastern and Chatham Railway.

As far as the drawings show, these non-balanced valves are all made of bronze. Figures 108 to 110 show the non-balanced Trick flat valve used on the above-mentioned locomotives of the Paris-Lyons-Mediterranean Railway; in order to reduce friction, white-metal liners are used.

Relieved or balanced flat slide valves are used on the Baden State Railway (2 B locomotive, and slow-pressure cylinder of the older 2 B 1 locomotive), on the French Northern Railway (low-pressure cylinder of the 2 B 1 locomotive, and all cylinders of the 2 C locomotive), on the French State Railway (high-pressure cylinders of the 2 B 1 locomotive), and on the Midi Railway (high-pressure cylinder of the 2 C 1 locomotive).

The balancing device of the Baden State Railway has a coned ring, which is automatically applied by the pressure of the steam (see figs. 111 and 112); the slide valve is made of cast iron.

Figures 113 to 116 show the balanced flat slide valves of the French Northern Railway. The circular relieving surface is made tight internally by cast-iron spring rings, and towards the top by four strong steel springs. The valve consists of bronze, the balancing plate of cast iron. The balanced slide valve of the French State Railway is of very similar design.

In the case of the balanced flat slide valve used on the Lancashire and Yorkshire Railway, four cast-iron straight edges, which are in steam-tight contact, are pressed against the relieving surface by steel springs placed below (see figs. 117 to 119). The body of the valve is made of bronze.

β) **Piston valves.**

Besides the flat slide valves, piston valves are also to be found, particularly in the case of more recent locomotives; these piston valves are of varying design and are used both for high-pressure and for low-pressure cylinders. Among such piston valves with single admission, we may mention the high-pressure valve (fig. 120) used on the 2 C superheated-steam locomotive (figs. 30 and 31) of the Belgian State Railway. The are two cast-iron spring rings A and B in each half of the valve; these take on the inside against a solid ring C, and are pressed against the port faces not only by their own elasticity, but also by the steam which can enter by the holes *ll*. The contact surfaces at *a*, *b*, *c* and *d* are ground true, so that they are steam-tight.

Figure 121 shows the piston valve, with internal admission, of the Swedish State Railway. A spring ring, in one piece, made of cast iron, is used; the rings are held and guided by ring shaped projections in the body of the piston, which

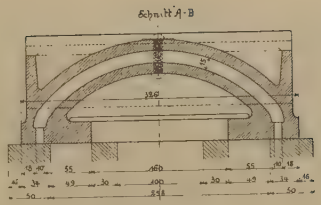


Fig. 108.

Fig. 109.
Section C-D.

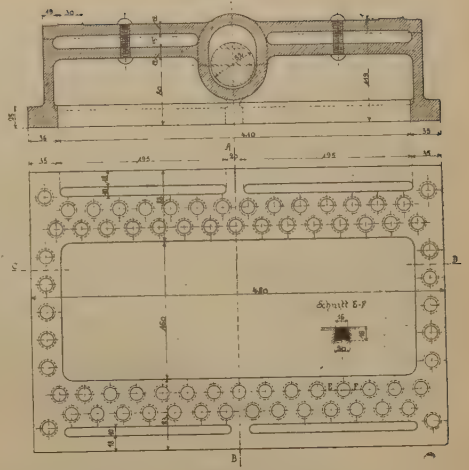


Fig. 110.

Figs. 108 to 110. — Group 3, γ, 1. — Paris-Lyons-Mediterranean Railway. — Flat slide valve.

Explanation of German term : Schnitt = Section.

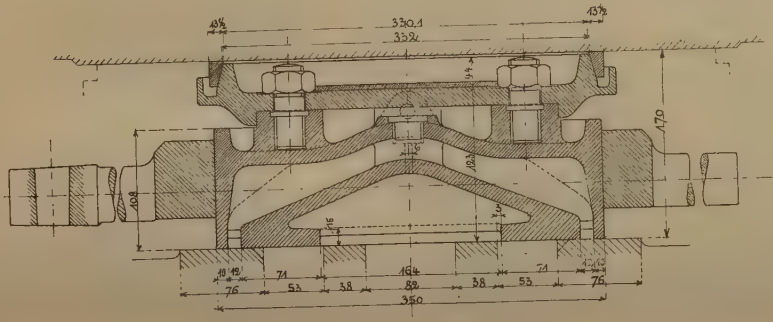


Fig. 111.

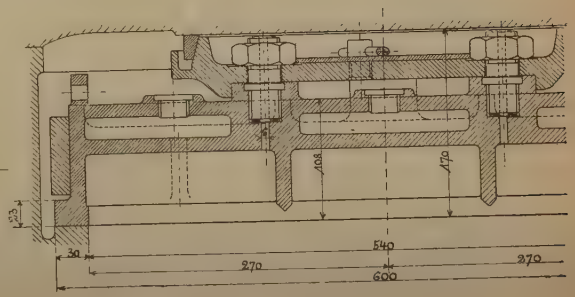


Fig. 112.

Balanced flat slide valve of the Baden State Railway.

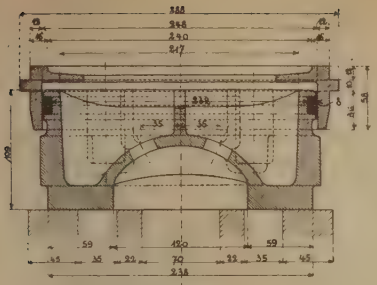
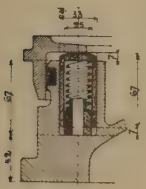


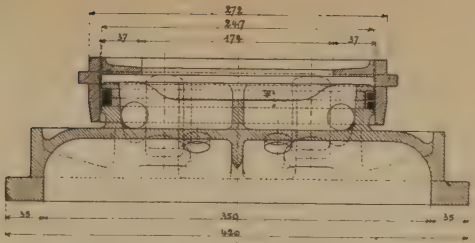
Fig. 113.



Section A-B-C.

Fig. 116.

Fig. 114.



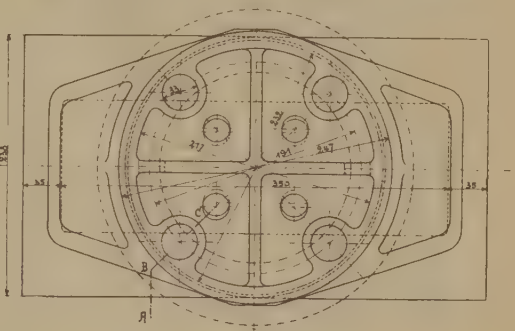


Fig. 115.

Figs. 113 to 116. — Group 4, α, 2. – Balanced flat slide valve of the French Northern Railway.

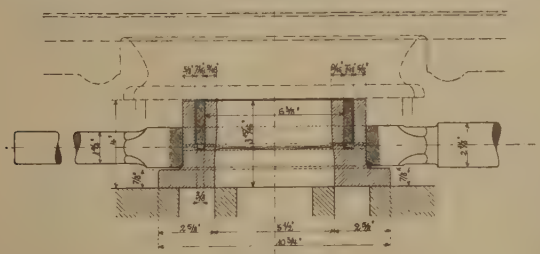


Fig. 117.

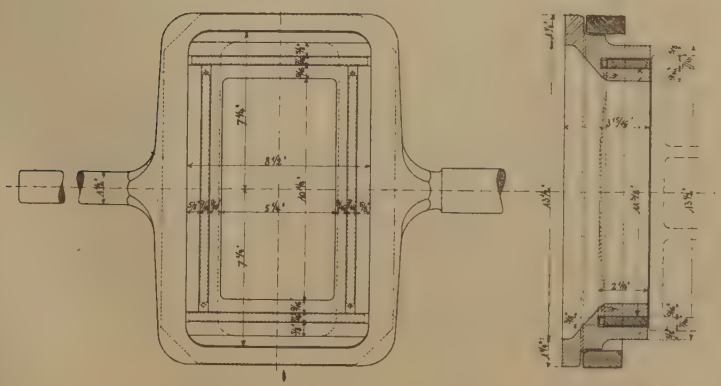


Fig. 118.

Fig. 119.

Figs. 117 to 119. — Group 4, γ, 4. — Balanced flat slide valve of the Lancashire & Yorkshire Railway.

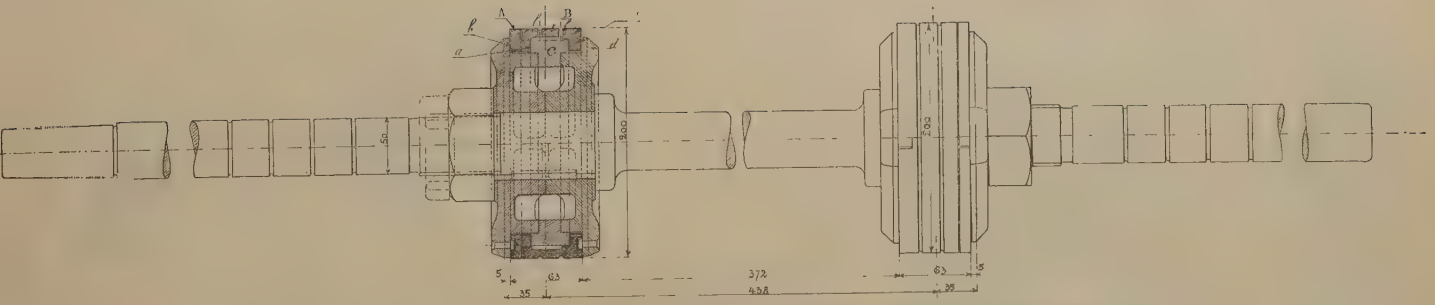


Fig. 120. — Group 3, α. — Piston valve of the $\frac{2}{3}$ C locomotive of the Belgian State Railway.

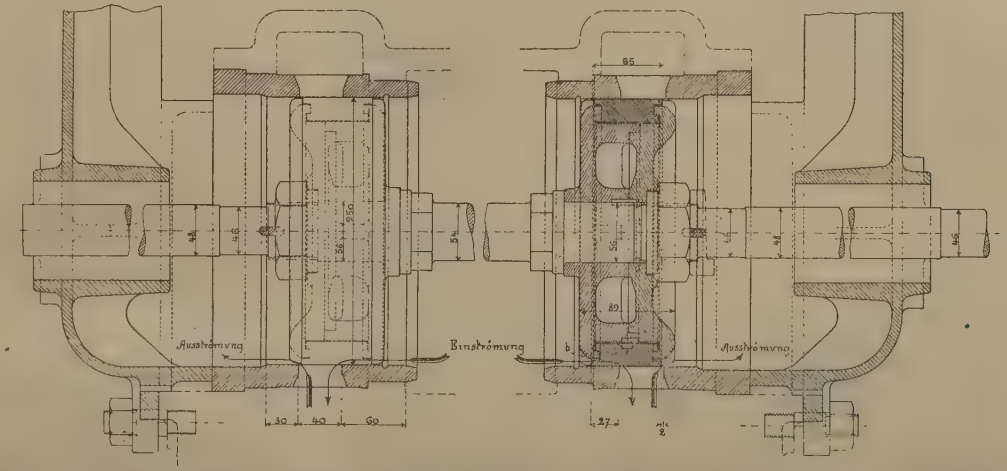


Fig. 121. — Group 2, δ. — Piston valve of the 2 B 1 locomotive of the Swedish State Railway

Explanation of German terms: Ausströmung = Exhaust. — Einströmung = Admission.

take into corresponding grooves in the spring rings. Steam entering the opening *b* reaches the back of the ring and helps to keep it tight.

The piston valve used by the Paris-Lyons-Mediterranean Railway on those of its locomotives which are so equipped is shown in figures 122 and 123. Two small spring rings, made of cast-iron, serve as packing; they take against a central ring made of the same material, which is grooved but not cut through. Very similar is the piston valve of the 2 C locomotive of the French Eastern Railway and that of the Great Western Railway, which is shown in figures 124 to 126.

Figure 127 shows the piston valve, with internal admission, of the 2 C locomotive of the Swedish State Railway. In this case there is a spring ring A, made of cast iron, with a groove on each side; in each of these grooves there is a solid steel ring. The surface of the spring ring as well as the parts of the piston body next to its sides have grooves turned in. The packing ring can move vertically between these surfaces. Holes *s* with oil grooves are provided for lubrication. The development of the valve as a Trick valve, by means of the ports $K_1 K_2$, is of particular interest. As soon as the valve has moved so far towards one side, for instance to the right, that edge 1 of the valve passes beyond edge 2 of the port face, to the right, so that steam now enters between edges 1 and 2, edge 3 in the left half of the valve also is further away from edge 4 of the valve. Live steam can now also enter between edges 3 and 4 into port K_2 and reach through this and the hollow body of the piston the right-hand admission port of the port face, so that the clear cross-section through which admission takes place is increased.

Double admission and exhaust is applied still more thoroughly in the case of the low-pressure cylinders of the 2 C 1 locomotive (figs. 41 to 43) of the Baden State Railway, as shown in figure 128. Each of the two drums which form a valve gives four hollow spaces; two of these in each case serve as extra ports for the steam which enters or goes out. Spring rings made of cast iron serve as packing rings at these places, which take over each other, and under them are flat steel rings; at the extra ports there are in each case two spring rings, made of cast iron, of square cross-section.

Finally figure 129 shows the combined high-pressure and low-pressure slide valve of the 2 B 1 locomotive of the Danish State Railway. This design has the advantage that only one valve motion is necessary at each side of the four-cylinder compound locomotive. The packing consists of spring rings made of cast iron.

All the four kinds of piston valves described work in simple cast-iron chests, not heated; no mention, even in the case of superheated-steam locomotives, is made in the answers of heated chests.

b) Piston speed.

Figures for the piston speeds of the individual locomotives were worked out, and are given in colums 39 to 41 of appendices 2 to 4. Column 39 gives the figure corresponding to a speed of 100 kilometres (62 miles) per hour, and column 41 the figure corresponding to the highest train speeds reported by the railway in question, the speeds in question being

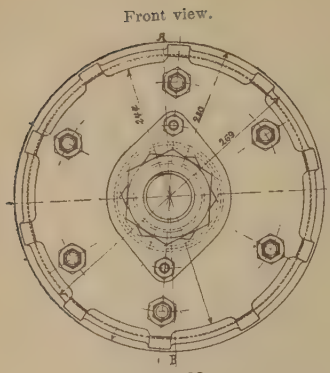


Fig. 123.

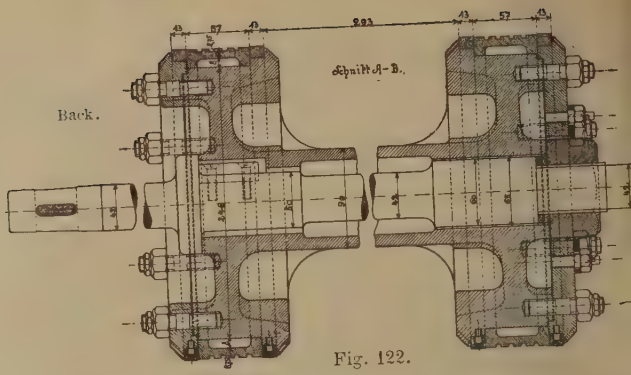


Fig. 122.

Figs. 122 and 123. — Group 3, γ. — Piston valve of the Paris-Lyons-Mediterranean Railway

Explanation of German term : Schnitt = Section.

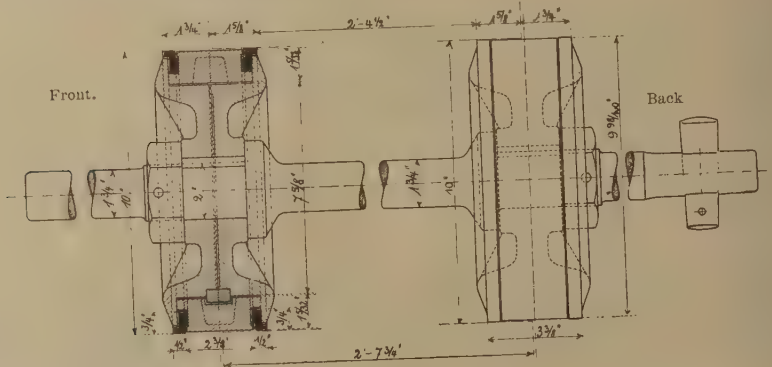


Fig. 124.

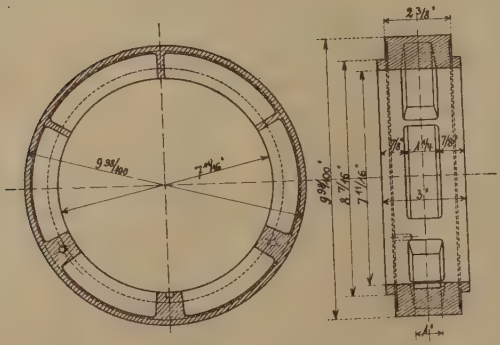


Fig. 125. Fig. 126.

Figs. 124 to 126. — Group 4, β, 3. — Piston valve of the Great Western Railway.

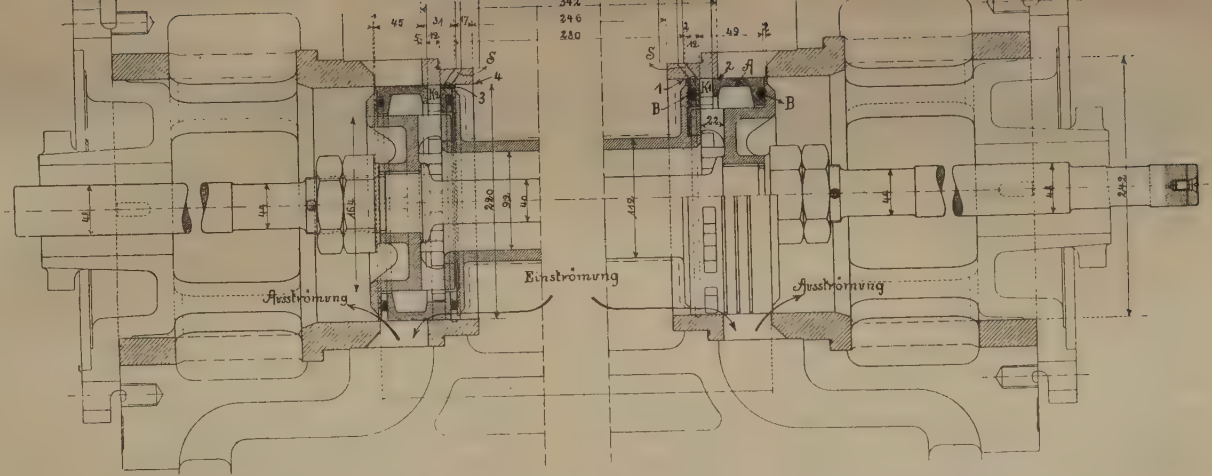


Fig. 127. — Group 2, δ. — Piston valve of the 2 C locomotive of the Swedish State Railway.

Explanation of German terms: Ausströmung = Exhaust. — Einströmung = Admission.

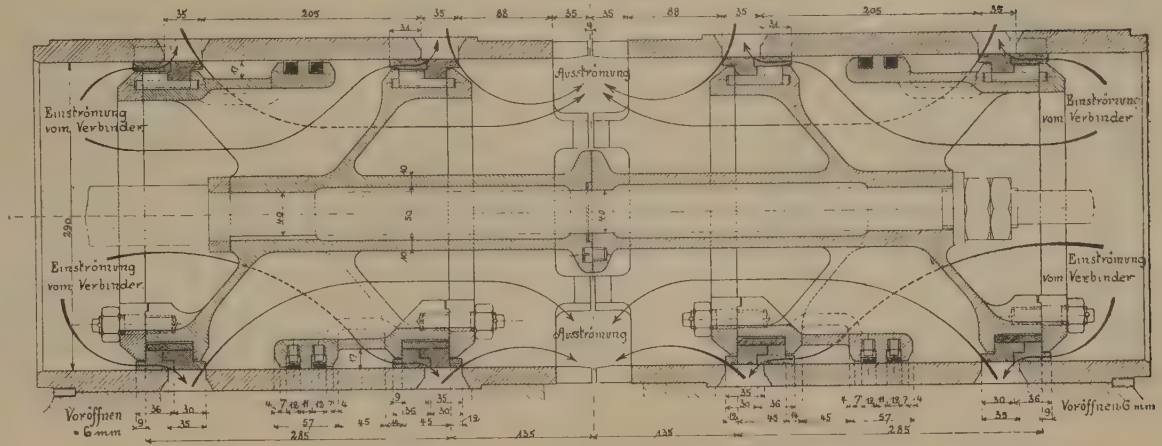


Fig. 128. — Group 3, γ. — Piston valve of the 2 C 1 locomotive of the Baden State Railway.

Explanation of German terms: Ausströmung = Exhaust. — Einströmung vom Verbinder = Admission from receiver. — Voröffnen = Lead.

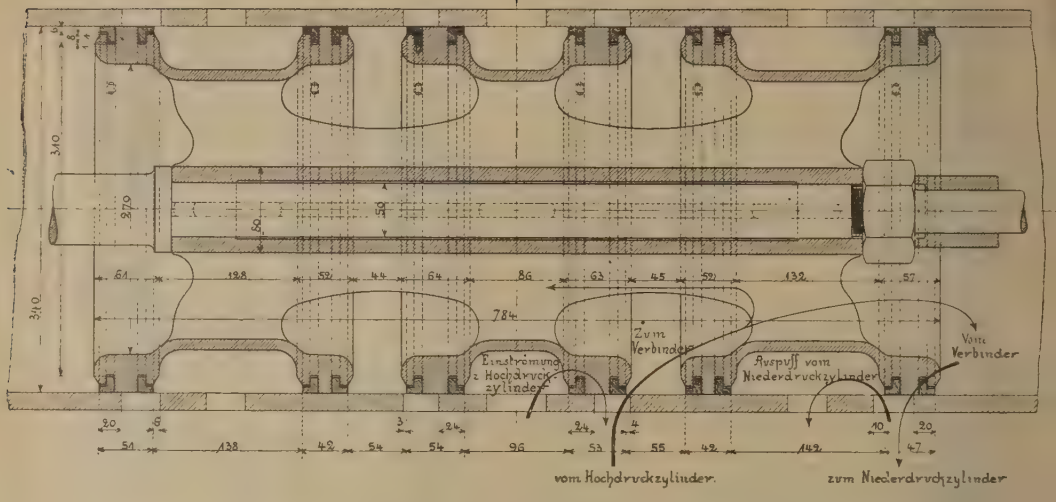


Fig. 129. — Group 2, α.
Double piston valve of the 2 B 1 locomotive of the Danish State Railway.

Explanation of German terms: Auspuff vom Niederdruckzylinder = Exhaust from low-pressure cylinder. — Einströmung z. Hochdruckzylinder = Admission to high-pressure cylinder. — Vom Hochdruckzylinder = From high-pressure cylinder. — Vom Verbinder = From receiver. — Zum Niederdruckzylinder = To low-pressure cylinder. — Zum Verbinder = To receiver.

given in column 40. Considering these results as a whole, we find that the piston speeds corresponding to the train speed of 100 kilometres (62 miles) per hour vary between 5·06 and 7·22 metres (between 16 ft. 7 1/4 in. and 23 ft. 8 5/16 in.) per second, the lower limit applying to the 2B locomotive of the Baden State Railway, with two inside cylinders, and the upper to the 2B1 tank locomotive of the Great Western Railway.

No well-defined or even approximate relation between the piston speeds and the design of the locomotives, for instance according to position and number of cylinders, could be determined. On the contrary, comparatively-high piston speeds, of 5 to 6 metres (16 ft. 5 in. to 19 ft. 8 in.) per second when the train speed is 100 kilometres (62 miles) per hour, are observed both in the case of locomotives with two outside cylinders (a less favourable design from this point of view) and in that of locomotives with inside cylinders, or with inside and outside cylinders; while on the other hand lower piston speeds, hardly exceeding 5 metres (16 ft. 5 in.) per second, are even to be found in the case of four-cylinder locomotives with pistons moving in the opposite direction to each other. The maximum piston speeds, for a train speed exceeding 100 kilometres (62 miles) per hour, are attained on the one hand by the 2B1 locomotive of the Belgian State Railway, which has only two outside cylinders, with 6·29 metres (20 ft. 7 5/8 in.) per second when running at 110 kilometres (68·4 miles) per hour, on the other

by the 2 C locomotive of the French Northern Railway, which has four cylinders and pistons moving in the opposite direction with each other, with 7·77 metres (25 ft. 6 in.) per second when running at 120 kilometres (74·5 miles) per hour. The highest piston speed, 9·21 metres (30 ft. 2 5/8 in.) per second, is attained by the 2 B 1 tank locomotive of the Great Western Railway, which has outside cylinders, and runs at 129 kilometres (80·2 miles) per hour.

c) Number of revolutions.

Similarly to the piston speeds, the numbers of the revolutions, per minute, of the driving and carrying wheels, are calculated for a train speed of 100 kilometres (62 miles) per hour, and for the highest train speeds reported, and the results are tabulated in appendices 2 to 4, columns 42 to 47.

α) Driving wheels.

The figures for the driving-wheel revolutions show much smaller differences than those for the piston speeds; in this case also, no definite or approximate relation between the number of the revolutions and the design of the locomotives could be found. The number of revolutions corresponding to a speed of 100 kilometres (62 miles) per hour varies between 240 and 195 per minute. The absolute maximum of 364 revolutions per minute is attained by the four-cylinder 2 C locomotive of the French Northern Railway when running at 120 kilometres (74·5 miles) per hour.

β) Carrying wheels.

In this case the figures for the revolutions show much greater differences than in the case of driving wheels. For leading carrying wheels they vary between 409 and 624 per minute, when running at 100 kilometres (62 miles) per hour. The absolute maximum is again attained by the 2 C locomotive of the French Northern Railway, namely 750 revolutions per minute when running at 120 kilometres (74·5 miles) per hour. As regards trailing carrying wheels, which as a rule can have a larger diameter than the wheels of a leading bogie or of a leading axle, the number of revolutions is generally less (see appendices 2 to 4, columns 46 and 47).

d) Balancing the masses and centrifugal forces.

The balancing of the moving masses, both of the eccentrically-placed rotating masses and of the reciprocating masses, in so far as these are at all balanced, is in all cases effected by balance weights, which are applied in the well-known way to the wheels. While the rotating masses, as far as our information shows, are balanced completely everywhere, matters are very different as far as reciprocating masses are concerned.

Considering in the first place locomotives with two outside cylinders, we find that with the 2 B locomotives of the Paris-Lyons-Mediterranean Railway (figs. 51 and 52), only 5·6 per cent of the reciprocating masses are balanced; this corresponds at a speed of 120 kilometres (74·5 miles) per hour to a centrifugal force of about 340 kilograms (750 lb.). On the other hand, with the 2 B 1 locomotive of the same railway (figs. 55 and 56) built in America, 29 per cent of these masses are balanced; this corresponds at a speed of 120 kilometres (74·5 miles) per hour to a centri-

fugal force of about 1,300 kilograms (2,866 lb.) (equal to 15 or 16 per cent of the static wheel-load).

With locomotives with two inside cylinders, the balancing of the reciprocating masses varies between 25 per cent (Baden State Railway, 2 B locomotive), which corresponds to an additional wheel-load of 8·3 per cent due to centrifugal force, and 67 to 70 per cent (Great Eastern Railway, Great Western Railway, Lancashire & Yorkshire Railway).

On the locomotives, with two inside cylinders, of the Swedish State Railway, 30 per cent of the reciprocating masses are balanced; and 50 per cent on those of the Belgian State Railway, the Caledonian Railway, the North Eastern Railway and the South Eastern & Chatham Railway.

Only a few three-cylinder locomotives are reported; on the 2 B 1 locomotive of the Great Central Railway 83 per cent of the reciprocating masses are balanced, in the proportion of driving axle, 50 per cent, coupled axle 33 per cent. The centrifugal force corresponding to the speed of 120 kilometres (74·5 miles) per hour is given as 7·37 tons. The percentage on the three-cylinder 2 B locomotive of the Midland Railway seems similar.

The reciprocating masses are not balanced at all on the four-cylinder locomotives of the German and of most of the French lines. They are satisfied with the balancing which results from the opposite directions in which the pistons move. Accordingly no centrifugal forces are produced in the case of these locomotives. On the other hand, the Belgian State Railway balances the whole of the reciprocating masses on its four-cylinder compound locomotives, although the pistons move in opposite directions. The same is the case with the 2 B locomotive of the Midi Railway; the centrifugal force accordingly amounts, at speeds of 120 kilometres (74·5 miles) per hour, to 11 or 12 per cent of the static wheel-load.

The 2 B locomotives of the French Northern Railway (figs. 79 and 80) have 30 per cent of the reciprocating masses balanced; the resulting centrifugal force does not exceed 10 per cent of the wheel-load even at the speed of 120 kilometres (74·5 miles) per hour.

e) Locomotive and tender brakes.

On a great number of locomotives, particularly on those of more recent construction, not only the driving axles, but also all the carrying axles, both those in the leading bogie, and the trailing carrying axles, are braked. This is the case with the locomotives of the Belgian State Railway, the Danish State Railway and the Bavarian State Railways, with the 2 B 1 and 2 C 1 locomotives of the Baden State Railways, with the 2 C locomotives of the French Northern Railway and the French Eastern Railway, and with the more recent locomotives of the Paris-Lyons-Mediterranean Railway and of the Orleans Railway. The trailing carrying axles of the most recent locomotives of the last railway are only braked if they have no lateral play.

All the axles of the locomotives of the Swedish State Railway and of the Hungarian State Railway are also braked. Some of the railways specially emphasize that it is considered necessary, or that it has been proved to be necessary (Bavaria, Sweden, Hungary) that all the axles of such high-speed locomotives should be

braked; the Great Western Railway also expresses the opinion that it is advisable that all axles should be braked. The coefficient of braking (ratio of pressure of the brake blocks to total weight of locomotive in working order) of these locomotives (tender excluded), which have all axles braked, varies between 47 and 82 per cent. The 2 B 2 locomotive of the Bavarian State Railway (fig. 12), forms an exception; this has a quick-acting brake which is so arranged that at the beginning of the braking the brake pressure can be increased to 114 per cent.

A second group includes those railways on which only part of the locomotive wheels are braked. As a rule, these are the driving and coupled wheels, sometimes also the trailing carrying wheels, while the bogie wheels of these locomotives are as a rule not braked. This is the case with the locomotives of the French State Railway, the Midi Railway, the older designs of the Baden State Railway, the French Northern Railway, the Paris-Lyons-Mediterranean Railway and the Orleans Railway, and also with the locomotives of the English railways. The coefficient of braking varies between 30 and 60 per cent.

All the axles of the tenders are braked, in nearly all cases. Referred to the weight of the tender, half-full, the brake pressure varies between 36 and 104 per cent. The tender of the above mentioned 2 B 2 locomotive of the Bavarian State Railway is equipped with a quick-acting brake, which at the beginning of the braking gives a brake pressure of 130 per cent, referred to the weight of the tender half-full.

On the Belgian State Railway, on the Orleans Railway and on the Caledonian Railway, the brake pressure on the tender wheels is 100 per cent, referred to the weight of the tender, empty.

f) Lubrication

On the large majority of the railways appliances are used for lubricating the cylinders and slide valves, so arranged that the lubricant is delivered from one centre to a number of different points (central lubrication). As a rule, oil presses and oil pumps, sight-feed lubricators operated by condensed water, etc., are used, which are operated either by one of the working parts of the locomotive, so that the amount of the lubricant supplied depends on the speed of the locomotive, or can be adjusted by hand so that a given number of drops are supplied per unit time. While oil pumps and oil presses predominate on the railways on the continent, condensation sight-feed lubricators seem more usual in England. A very centralized appliance for lubricating the many points of lubrication of the cylinders and slide valves of a four-cylinder compound locomotive is shown in figures 130 to 132 (2 C 1 locomotive of the Baden State Railway). The lubricating material is sent to the different points by two oil pumps, each tenfold. The pumps are so arranged that the quantity of oil supplied to all points of lubrication can be varied simultaneously; and apart from this, the quantity delivered at each point can be adjusted, within certain limits, as required.

VII. — Final considerations.

If we consider the whole results of our enquiry, we find in the first place, that among all the countries with which this

report deals (all countries affiliated to the International Railway Congress, except America), countries in Europe are the only ones in which trains run with speeds of 100 kilometres (62 miles) per hour.

Running speeds. — In Europe, even such speeds are only attained in regular working, up to the limit of 129 kilometres (80·2 miles) per hour, on the French and British railways included in group 4 (see appendix 4, column 4); in addition speeds of up to 120 kilometres (74·5 miles) per hour are attained in exceptional cases, such as lateness, etc., on the Belgian, German, French and British railways included in group 3.

Arrangement of the locomotive axles. — As regards the locomotives used for attaining these high speeds, by far the most usual arrangement is to have a leading bogie; the different types of the kind used are 2A1, 2B, 2B1, 2B2, 2C and 2C1. On a few railways, we also find locomotives with only one leading carrying axle, for instance the 1B locomotives of the Paris-Lyons-Mediterranean Railway and on the Great Western Railway, as well as the 1C1 tank locomotives of the latter railway. This locomotive, and also another 2B1 type, also on the Great Western Railway, are the only tank locomotives reported for speeds exceeding 100 kilometres (62 miles) per hour.

The bogie trucks or leading carrying axles all have more or less lateral play; the return to the central position is ensured by such well-known means as check springs, swing links, etc. On most railways, the trailing carrying axles also have lateral play; this is only absent in a few cases. On several English railways, the driving axles have also a little lateral play.

Number and position of steam cylinders. — As regards the number of cylinders, two-cylinder and four-cylinder locomotives are represented approximately equally, but among the locomotives most recently built there are more four-cylinder locomotives; locomotives with three cylinders are only used to a limited extent, on two English railways, for the purposes here considered.

As regards countries, the two-cylinder locomotive predominates in England, while but few of these locomotives are used on Belgian, German, French and Swedish railways. The opposite is the case with four-cylinder locomotives, which are more common on the railways on the continent of Europe, particularly in France. The two-cylinder locomotives have inside cylinders in the great majority of cases; in only about 10 per cent of the locomotives reported are the cylinders outside.

The four-cylinder locomotives have two inside and two outside cylinders, without exception. There are no cases of designs with cylinders placed one over the other, or placed one behind the other and acting on the same cross-head (Vauclain or tandem type).

As far as four-cylinder compounds are concerned, the low-pressure cylinders are inside and the high-pressure cylinders outside, in the majority of the locomotives. On the French railways, the rule is that the low-pressure cylinders are inside. The Italian locomotives reported have the two high-pressure cylinders on the left, and the two low-pressure cylinders on the

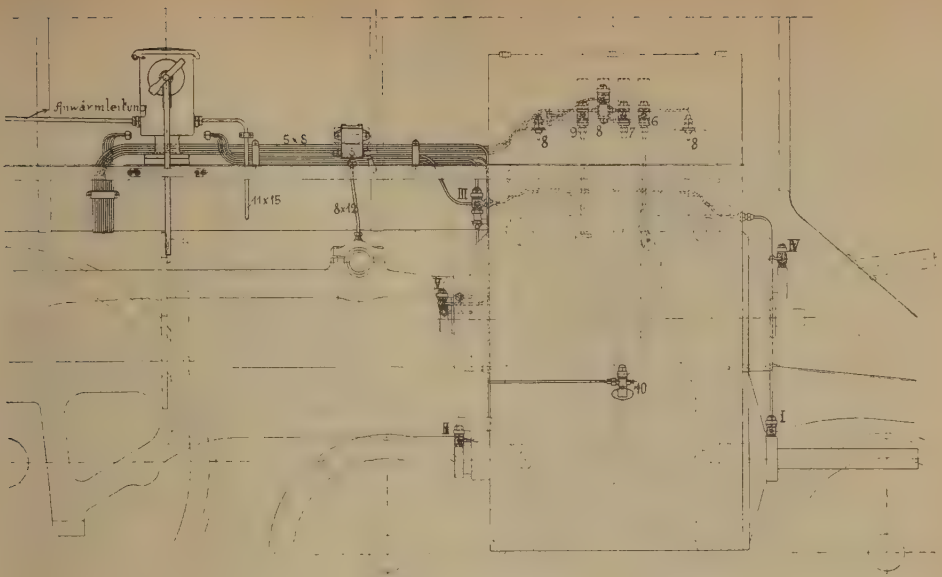


Fig. 130.

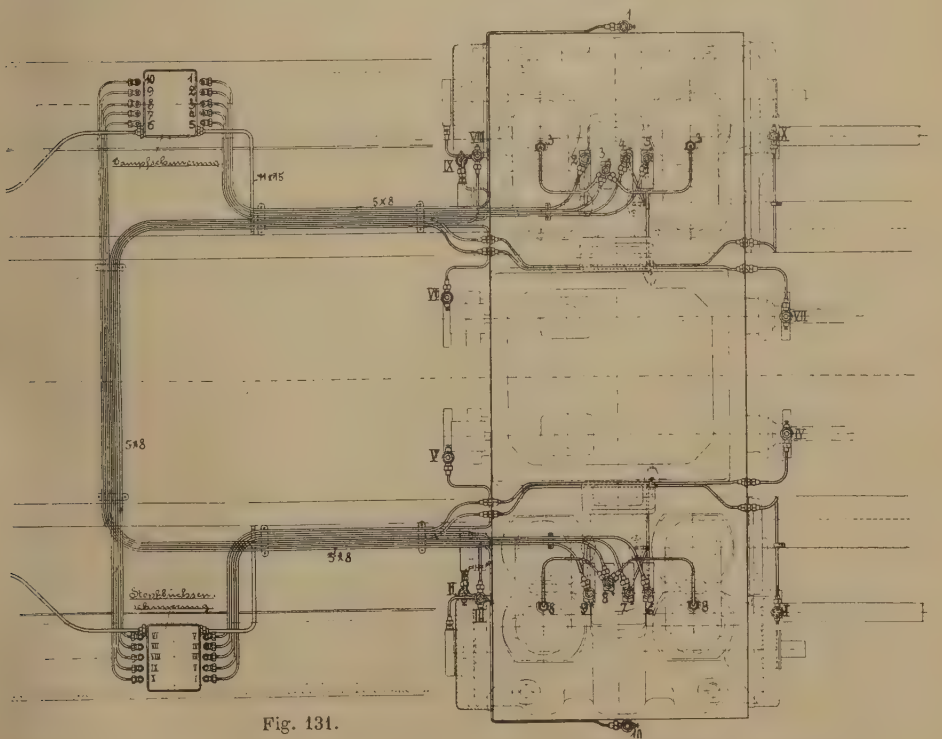


Fig. 131.

Figs. 130 to 132. — Group 2, β. — Central lubrication for the cylinder of the 2 C 1 locomotive of the Baden State Railway.

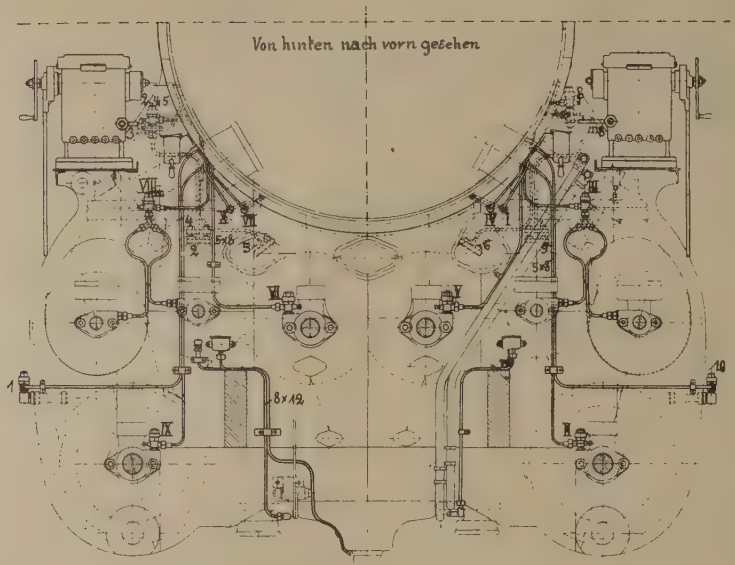


Fig. 132.

Figs. 130 to 132 (*continuation*). — Group 2, β. — Central lubrication for the cylinders of the 2 C 1 locomotives of the Baden State Railway.

Explanation of German terms : Anwärmleitung = Heating pipe. — Dampfschmierung = Steam lubrication. — Stopfbüchsenschmierung = Stuffing-box lubrication. — Von hinten nach vorn gesehen = View from back towards front.

List of the points of lubrication and the pipes of locomotive IV f. 2.

Left oil pump. Steam lubrication.

Pipe No. 1	Left low-pressure cylinder.
— No. 2	— high-presure valve, back.
— No. 3	— low-pressure valve, back and front.
— No. 4	— high-pressure valve, front.
— No. 5	— high-pressure cylinder.
— No. 6	Right high-pressure cylinder.
— No. 7	— high-pressure valve, front.
— No. 8	— low-pressure valve, back and front.
— No. 9	— high-pressure valve, back.
— No. 10	— low-pressure cylinder.

Right oil pump. Stuffing-box lubrication.

Pipe No. I	Right low-pressure piston-rod stuffing-box, front.
— No. II	— — — — back.
— No. III	— high-pressure and low-pressure valve-rod, stuffing-boxes, back.
— No. IV	— high-pressure piston-rod stuffing-box, front.
— No. V	— — — — back.
— No. VI	Left — — — —
— No. VII	— — — — front.
— No. VIII	— high-pressure and low-pressure valve-rod stuffing boxes, back.
— No. IX	— low-pressure piston-rod stuffing-box, back.
— No. X	— — — — front.

right side of the locomotive, one being inside and the other outside in each case. The three-cylinder locomotives, which are all compounds, have one inside high-pressure cylinder and two outside low-pressure cylinders.

System of expansion. — The two-cylinder locomotive are chiefly non-compounds; especially is this the case with the Swedish and English locomotives of this kind, which are all non-compounds.

On the contrary compounding predominates in the case of four-cylinder locomotives; there are only two varieties which are exceptions.

The two varieties which have four cylinders and are non-compounds (Belgian State Railway and Great Western Railway), both use superheated steam.

Working pressure. — Low pressures, of from 10 to 12 atmospheres, are only found in a few cases; medium pressures, of nearly 13 and of 14 atmospheres, are more frequent, particularly in the case of the English locomotives, where 12·7 atmospheres is the rule. The highest pressures, of 15 and 16 atmospheres, are found on nearly all the French and German locomotives, and also on Belgian, Danish, Italian and Hungarian locomotives; but there are only very few instances in the case of English locomotives.

Wet steam and superheated steam. — The older wet-steam principle is the rule; superheated-steam locomotives form the exception. Taking it altogether, only two Belgian, four German, one English and one Swedish superheated-steam locomotives have been reported; several administrations are at present building superheated-steam locomotives for high speeds. The German superheated-steam locomotives are all four-cylinder compounds; all the other superheated-steam locomotives are non-compounds, and have either two cylinders (Belgium and Sweden), or four (Belgium and Great Britain).

Heating surface and grate area. — As regards size, boilers having a heating surface of from 150 to 250 square metres (1,614·65 to 2,691·08 square feet), and even more, are by far the more usual. Smaller boilers, of heating surfaces down to 100 square metres (1,076·43 square feet), are rare exceptions. The grate area varies considerably; it is evident that this is much influenced by the quality of the fuel; this is shown by the comparatively-small grates of the English locomotives, and of some of the Continental locomotives which use English coal. The length of the grate, on the large majority of the locomotives, does not exceed 2·5 metres (8 ft. 2 $^{7}/_{16}$ in.). Grates longer than 3 metres (9 ft. 10 in.) are only found in very few cases. When a larger grate is required, the plan generally adopted is to have a wider fire-box, either standing on the frame between the wheels, or also extending beyond them.

Smoke tubes. — Most of the railways use smooth tubes having an external diameter of 45 to 55 millimetres (1 $^{25}/_{32}$ to 2 $^{5}/_{32}$ inches). Wider tubes with ribs inside (Serve tubes) predominate on the French locomotives, and are also used on one Belgian locomotive.

The length between tube-plates does not as a rule exceed 5 metres (16 ft. 5 in.). Lengths of nearly 6 metres (19 ft. 8 in.), or a little more, are used in a few cases.

The length of the ribbed tubes varies as a rule between 3·5 and 4·5 metres (between 11 ft. 6 in. and 14 ft. 9 in.).

Drive (four-cylinder locomotives). — On the four-cylinder locomotives, the connecting rods either all act on the same driving axle (as a rule the first), or those of the inside cylinders act on the first and those of the outside cylinders on the second, the two being connected by coupling rods (de Glehn design). The latter design is used on all the French, on some of the Danish, and on one of the English four-cylinder locomotives, while the single-axle drive is found on the Belgian, on the German, on the Italian, on the Hungarian and on one of the English four-cylinder locomotives.

Locomotive weights and wheel-loads. — The weights of the locomotives, in working order, vary much, according to design; the lowest figure is 43,000 kilograms (94,800 lb.), for the 2B two-cylinder locomotive of the French Northern Railway, and the highest is 90,400 kilograms (199,300 lb.), for the 2C1 four-cylinder locomotive of the Midi Railway. The adhesive weights, in the case of locomotives with two driving axles, vary between 28,600 and 39,800 kilograms (between 63,050 and 87,740 lb.) (2B two-cylinder locomotives of the French Northern Railway, and 2B three-cylinder locomotive of the Midland Railway). In the case of locomotives with three driving axles, the lowest adhesive weight is 42,470 kilograms (93,630 lb.) (2C locomotive of the French Northern Railway), and the highest 55,500 kilograms [122,350 lb.]) (2C locomotive of the Great Western Railway). Axle-loads, of driving axles, of less than 15,000 kilograms (33,100 lb.) are only found in a very few cases. Most of the locomotives have axle-loads, on driving axles, of 16,000 to 18,000 kilograms (35,270 to 39,680 lb.). Higher axle-loads are to be found on some Belgian, French and English locomotives. The maximum, about 20,000 kilograms (44,100 lb.) in round figures, is found on the 2B locomotive of the Midland Railway.

Heating surface per unit of weight. — The figures for the area of heating surface per unit of weight in working order show much less variation. With very few exceptions, the figures for the chief types lie within the following limits :

2B	2·24 to 3.5 square metres per ton (24.48 to 38.26 square feet per English ton of weight in working order).
2B1	2·46 to 3·3 square metres per ton (26·88 to 36·07 square feet per English ton) of weight in working order.
2C	2·2 to 3·3 squre metres per ton (24·05 to 36·07 square feet per English ton) of weight in working order.
2C1	2·77 to 3·1 square metres per ton (30·28 to 33·88 square feet per English ton) of weight in working order.

The maximum in this respect is found on the 2B two-cylinder locomotive of the Great Eastern Railway, namely 4 square metres per ton (43.72 square feet per English ton).

Appliances for reducing air resistance. — Appliances for reducing air resistance (wind-cutters) are to be found on locomotives of the Danish, German, French, Italian, Swedish and Hungarian railways.

They mostly consist of a conical or wedge-shaped extension at the front of the smoke-box, and of a wedge-shaped cab front.

Tender design. — Tenders with three axles predominate. The Danish and all the German locomotives have tenders with four axles; also a few of the English and French locomotives. An older 2 B locomotive of one of the French railways has a tender with two axles only.

In the case of tenders with four axles, there are as a rule two bogies. The Danish four axled tender is an exception, as all the axles are in one common frame, like ordinary axles; but the first axle and the third axles have lateral play. The water tanks are of the usual horseshoe or rectangular shape. The Hungarian 2 B 1 four-cylinder compound locomotive is the only one which has a Vanderbilt tender.

Water carried. — The great majority of the tenders take 15 to 20 cubic metres (3,300 to 4,400 English gallons) of water; 20 cubic metres (4,400 English gallons) is a very usual figure in the case of the most recent tenders. The greatest capacity is found on a four-axled tender of the Bavarian State Railway, namely 26 cubic metres (5,720 English gallons). Ramsbottom scoops for taking water *en route* are found in a few cases on French and English tenders.

Fuel carried. — The bunkers on most of the tenders can hold from 5,000 to 6,000 kilograms (11,030 to 13,230 lb.) of fuel. The tender of the 2 B locomotive of the Great Eastern Railway, which is designed for supplementary oil-firing, can take 3,360 pounds of coal and 715 gallons of liquid fuel, or else it can take a correspondingly-greater weight of solid fuel only.

Weight in working order. — Corresponding to these large capacities, the weights of these tenders, in working order, are considerable. In most cases the weight varies between 35,000 and 45,000 kilograms (between 77,200 and 99,200 lb.); but a very appreciable number of tenders are heavier, and the weight, in working order, runs up to 57,900 kilograms (127,650 lb.). If we compare the weight of the tender, empty, with the quantity of the water it can hold, we find that the old rule, according to which the weight of the tender, empty, is about equal to the weight of water it takes, is still generally applicable. But there are also tenders, in considerable numbers where this ratio is increased, that is to say the weight of the tender exceeds, more or less, the weight of water carried, while there are only very few tenders which, when empty, weigh less than the water they can carry.

APPENDIX 1.

Detailled list of questions relating to question VII.

QUESTION 1.

Types and numbers of locomotives for very high speeds.

Do you own steam locomotives, which in regular working haul trains at speeds exceeding 60 miles per hour?

A. How many types of
  a) locomotives with separate tenders?
  b) tank locomotives?
B. How many locomotives have you of class *A*, *a*) of each type?
  B, *b*) of each type?

QUESTION 2.

Particulars of the lines and of the speeds.

I. As regards the sections run over in regular working, at speeds exceeding 60 miles per hour, what are the :
  A. Lengths, in miles?
  B. Mean rising gradients, per mil?
  C. Maximum rising gradients, per mil?
  D. Mean falling gradients, per mil?
  E. Maximum falling gradients, per mil?
  F. Radii of the sharpest curves, in chains?

II. As regards the different sections to which the information given under I, *A* to *F*, applies, what are the :
  A. Mean . . } speeds exceeding 60 miles per hour attained in regular working?
  B. Maximum }

QUESTION 3.

Particulars of the trains hauled.

I. What are :
  A. The number of axles,
  B. The weight in tons of the trains regularly running on the sections mentioned in the answer to question 2 at the speeds there stated?

II. What are the particulars of the different carriages which as a rule compose these trains, as regards :
  A. The number of axles (carriages with two, three, four or six axles)?
  B. The existence of passages, entirely or partially enclosed (vestibules), leading from carriage to carriage?
  C. The weight of the different carriages?

QUESTION 4.

Time when set in operation, length of runs, annual mileage.

I. Since when are the locomotives mentioned in the answer to question 1 used in regular working for hauling trains at speeds exceeding 60 miles per hour?

II. What in these cases are the longest runs (in miles) made :
  A. By one locomotive without stop?
  B. Without change of locomotive?

III. What is the mean annual mileage (in miles)

per locomotive, including in the calculation :

A. The locomotives which must simultaneously be kept ready, so as to ensure the normal progress of the service of high-speed trains?

B. Also the locomotives used for the same service which at the time are being repaired?

QUESTION 5.

Chief particulars of the locomotives and tenders.

I. Locomotive :

A. Boiler.

a) Heating surface of fire-box, in square feet.

b) Heating surface of smoke tubes, in square feet.

c) Heating surface of superheater, in square feet.

d) Total heating surface $(a + b + c)$, in square feet.

e) Working pressure, in pounds per square inch.

f) Height of centre line of boiler above rolling surface of rails, in inches.

g) Length of smoke tubes between tube plates, in feet.

h) $\frac{\text{External}}{\text{Internal}}$ } diameter of smoke tubes, in inches.

i) $\frac{\text{External}}{\text{Internal}}$ } diameter of superheater, in inches.

k) Grate, clear length, in feet.

l) — — width, —

m) Grate area, in square feet.

B. Engine :

a) Number of high-pressure cylinders.

b) Position of high-pressure cylinders (whether inside or outside).

c) Diameter of high-pressure cylinders, in inches.

d) Length of stroke of high-pressure cylinders, in inches.

e) Number of low-pressure cylinders.

f) Position of low-pressure cylinders (whether inside or outside).

g) Diameter of low-pressure cylinders, in inches.

h) Length of stroke of low-pressure cylinders, in inches.

C. Axles :

a) Total number of carrying axles.

b) Number of carrying axles of bogies.

c) Number of driving axles.

D. Weights :

a) Weight of locomotive, empty, in pounds.

b) Weight of locomotive, in working order, in pounds.

c) Adhesive weight of locomotive, in pounds.

II. Tender :

A. Number of axles.

B. Stores :

a) Water, in gallons.

b) Fuel, in pounds.

C. Weight :

a) Weight of tender, empty, in pounds.

b) Weight of tender, in working order (fully equipped and fully loaded), in pounds.

III. Please send a sketch of the locomotive and tender, on a scale of about 1 : 50, showing the chief dimensions in inches and the different axle-loads in tons.

QUESTION 6.

Details of construction of the locomotives.

I. Superheater :

A. What type is used? (Please send sketches with explanations.)

B. When trains are hauled at speeds exceeding 60 miles per hour, by how many degrees Fahrenheit is the steam heated over and above the temperature of saturated steam?

C. What results are given by the superheater :

a) As regards the continuous maintenance of the degree of superheat required?

b) As regards the maintenance of its parts?

II. Valve gear :

A. What class of valve gear is used with the cylinders?

a) Flat slide valves :

α) Not balanced?

β) Balanced?

b) Piston valves :

α) With spring piston packing rings?

β) With non-elastic piston packing rings? and

1. With heated stuffing-boxes?

2. With non-heated stuffing boxes?

c) Valves?

d) Cocks?

Please supply drawings of the slide valves or their substitutes.

B. Have you any records of observations or trials of such valve gear, as regards keeping it tight and the maintenance it required?

III. Balancing the moving masses :

A. Are not only the eccentrically placed rotating masses of each driving wheel balanced, but also parts of the reciprocating masses, and if so what percentage of their total weight?

B. Is the partial balancing of the reciprocating masses effected by :

a) Rotating masses forming part of the driving wheels?

b) Or by what other method?

C. How great is the centrifugal force resulting from the balancing of the reciprocating masses by rotating masses added to the driving wheels, at the greatest regular speed (which please again mention here) of the locomotive?

IV. Passage of curves :

A. What is the rigid wheel-base of the locomotive?

B. Which bogies, carrying axles or driving axles have any lateral play, and how much lateral play (in inches) is there from the centre to each side?

C. What is the radius in chains of the sharpest curve which owing to this play of its axles the locomotive can still run over?

V. Lubrication :

A. Is central lubrication used for certain groups of the moving parts of the locomotives, and if so, for which?

B. In these lubricating appliances, how is the amount of lubricant supplied regulated according to the work of the locomotive?

VI. Brakes :

A. As regards this high-speed traffic, is it considered necessary that it should be possible for all the locomotive wheels to be braked, or only some of them?

B. What is the coefficient of braking, or the ratio of the total pressure of the brake blocks on the :

a) Locomotive wheels;

b) Tender wheels;

To the weight,

a) Of the locomotive, in working order?

b) Of the tender, half-full?

VII. Miscellaneous :

Are there :

A. On the locomotives;

B. On the tenders,

any special arrangements of the running or driving gear, made necessary by high the speeds, and of what do they consist?

QUESTION 7.

Fuel.

I. Is fuel of a special quality in regular use for the locomotives working at these high speeds, or is the same fuel used as on the other locomotives?

II. What is the quality and the calorific value in thermal units of the fuel regularly used when hauling high-speed trains?

QUESTION 8.

Results of trials.

If you have any records of trials or performances of locomotives hauling trains at speeds exceeding 60 miles per hour, and of the corresponding consumptions of fuel, water and lubricant, please give details.

QUESTION 9.

Final remarks.

Every drawing annexed to the answer should be legibly marked in its upper right hand corner with the name of the railway answering.

It is also requested that only drawings consisting of black lines drawn on white paper or on white tracing cloth should be sent, sufficiently well executed to enable them to be reproduced photographically on a reduced scale.

Appendix 1.

Group 1.

List of the railways which sent answers, but were unable to supply any information.

Index number	PART OF THE WORLD.	NAME OF RAILWAY.	Maximun speed, in kilometres (in miles per hour).
1	*Africa*	Central South Africa Government Railways	...
2	—	Lagos Government Railway	...
3	—	Natal Government Railways	...
4	*Asia*	Bengal Nagpur Railway	64.3 (40) (1)
5	—	Great Indian Peninsula Railway	96.5 (60)
6	—	Madras & Southern Mahratta Railway	...
7	—	North Western Railway (State Railway of India)	...
8	—	East Bengal Railway (State Railway of India)	72.3 (45)
9	—	East Indian Railway	...
10	—	Oudh & Rohilkhand Railway (State Railway of India)	...
11	—	Transbaikal Railway	58 (36)
12	*Australia*	New South Wales Government Railways	...
13	—	South Australia Government Railways	...
14	—	Tasmania Government Railways	...
15	*Europe:* 1. Germany	Oldenburg State Railway	...
16	— —	Prussian-Hessian State Railway	...
17	— —	Alsace-Lorraine State Railway	...
18	— —	Saxon State Railway	...
19	— —	Wurtemberg State Railway	...
20	— 2. Gr. Britain and Ireland	Glasgow & South Western Railway	...
21	— —	Great Southern & Western Railway	...
22	— 3. Holland	Dutch State Railway	...
23	— 4. Norway	Norwegian State Railway	...
24	— 5. Austria and Hungary	Aussig-Teplitz Railway	...
25	— — —	Austrian North Western Railway	...
26	— — —	Austrian State Railway	90 (56)
27	— — —	Austrian Southern Railway	100 (62)
28	— — —	Kaschau-Oderberg Railway	...
29	— 6. Russia	Moscow-Kursk Nijni and Murom Railway	...
30	— —	Moscow-Windau-Rybinsk Railway	80 (50)
31	— —	Nicolas Railway	...
32	— —	Russian Northern Railway	76.8 (47.7)
33	— —	Riga-Orel Railway	85 (52.8)
34	— —	Riazan-Ural Railway	...
35	— —	Sizran Wiazma Railway	51.2 (31.8)
36	— —	Trancaucasus Railway	...
37	— —	Warsaw-Vienna Railway	...
38	— 7. Switzerland	Swiss Federal Railway	90 (56)
39	— —	St. Gothard Railway (formerly)	90 (56)
40	— 8. Servia	Servian State Railway	...
41	— 9. Spain	Andalusian Railway	...
42	— —	Spanish Northern Railway	...

(1) Stops included.

*

Appendix 2. **Group 2.**

	COUNTRY.	Index number	RAILWAY.	DESIGN.	Number of illustration.	Boiler: Height of centre line of boiler above rolling surface of rails.	Working pressure, in lb. per square inch.	Heating surface in contact with hot gases. Fire-box, in square feet.	Smoke tubes, in square feet.	Superheater, in square feet.	Total, $a + b + c$, in square feet.	Tubes. Diameter of smoke tubes, internal, external, in feet and inches.	Diameter of superheater tubes, internal, external, in feet and inches.	Length between tube-
							p	a	b	c	H			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
α	*Denmark* .	1	Danish State Railway.	2 B 1 4-cylinder compound.	1-5 & 10	ft. in. 8. 8 5/16	213·0	130·0	2,070·00	...	2,200·00	0.2 / 0.1 13/16	...	15.
β	*Germany* .	1	Bavarian State Railw.	2 B 1 4-cylinder compound.	11	9. 4 13/16	227·6	156·1	2,058·00	...	2,214·10	0.2 1/16 / 0.1 7/8	...	14.
β	— .	1	— — —	2 B 2 4-cylinder superheated-steam compound.	12	9. 8 3/16	199·1	177·6	2,131·00	409·0	2,717·60	0.2 3/16 / 0.2 1/16	0.1 7/16 / 0.1 5/8	16.
β	— .	1	— — —	2 C 4-cylinder compound.	13	9. 2 1/4	227·6	156·1	2,058·00	...	2,214·10	0.2 1/4 / 0.1 7/8	...	14.
β	— .	1	— — —	2 C 4-cylinder superheated-steam compound.	13	9. 2 1/4	227·6	156·1	1,504·00	371·5	2,121·00	0.2 1/16 / 0.1 7/8	0.1 7/16 / 0.1 1/8	14.
β	— .	1	— — —	2 C 1 4-cylinder superheated-steam compound.	14	9. 4 3/8	213·0	157·1	2,192·00	538·0	2,887·10	0.2 3/16 / 0.2 7/16	0.1 7/16 / 0.1 3/8	17.
γ	*Italy* . . .	1	Italian State Railway.	1 C 1 4-cylinder compound.	15-19	9. 2 1/4	227·6	135·0	2,238·00	...	2,373·00	0.2 1/16 / ...	...	16.
δ	*Sweden* . .	1	Swedish State Railw.	2 B 1 2-cyl. superh.-steam.	20	9. 0 5/16	170·0	127·0	1,305·00	353·0	1,785·00	0.5 1/4 / 0.4 7/8 0.2 / 0.1 3/4	0.1 7/16 / 0.1 1/8	15.
δ	— . .	1	— — —	2 C 2-cyl. superh.-steam.	21	9. 0 5/16	...	...	...	...	...	...	...	15.
ε	*Hungary* .	1	Hungarian State Railw.	2 B 1 2-cylinder.	...	8.10 5/16	185·0	130·0	1,705·00	...	1,745·00	0.2 1/16 / 0.1 13/16	...	14.
ε	— . .	1	— —	2 B 1 2-cylinder compound.	...	8.10 5/16	185·0	130·0	1,705·00	...	1,745·00	0.2 1/16 / 0.1 13/16	...	14.
ε	— . .	1	— —	2 B 1 4-cylinder compound.	26	9. 4 3/16	227·5	119·0	2,430·00	...	2,530·00	0.2 1/16 / 0.1 13/16	...	17.

Abbreviations :

p_1 (for non-compound) = 0.5 p (col. 8).

p_1 (for compound) = $\alpha \cdot p$ (col. 8).

Ratio of capacity of cylinders.	1 : 2·0	1 : 2·25	1 : 2·5	1 :
α	0·44	0·42	0·40	0·

LOCOMOTIVE.

Grate.			Engine.															Running gear.				
			Steam cylinders.								Steam distribution.			Diameter of wheels, measured at tread.			Lateral play on each side of centre.				
			High pressure				Low pressure.					Type of valve.									
Clear width, in feet and inches.	Useful grate area, in square feet.		Number.	Position { inside (i), outside (o).	Diameter, in ft. and inches.	Length of stroke, in feet and inches.	Number.	Position { inside (i), outside (o).	Diameter, in ft. and inches.	Length of stroke, in feet and inches.	Type of motion.	High pressure.	Low pressure.	Leading bogie or leading carrying wheels, in feet and inches.	Driving wheels and coupled wheels, in feet and inches.	Trailing bogie or trailing carrying wheels, in feet and inches.	Leading bogie or leading carrying wheels, in feet and inches.	Trailing bogie or trailing carrying wheels, in feet and inches.			
	R				d	l			d	h					D						
17	18		19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34				
6. 4 3/8	34·8		2	i	1.1 3/8	1.11 5/8	2	o	1.10 7/16	1.11 5/8	H. W.	P. v.	P. v.	3. 5 1/2	6. 6 1/8	3. 5 1/2	...	0. 5/8				
3. 6 15/16	35·2		2	i	1.1 3/8	2. 1 3/16	2	o	1.10 7/16	2. 1 3/16	H. W.	P. v.	P. v.	3. 1 3/8	6. 6 3/8	3.11 1/2	0. 2 3/4	0				
6. 7 15/16	50·6		2	i	1.4 3/16	2. 1 3/16	2	o	2. 0	2 1 3/16	H. W	P. v.	P. v.	3. 3 5/8	7. 2 5/8	3. 3 5/8	0. 2 3/4	0.2 3/4				
3. 6 15/16	35·2		2	i	1.1 3/8	2. 1 3/16	2	o	1.10 7/16	2. 1 3/16	H. W.	P. v.	P. v.	3. 1 3/8	6. 1 5/8	...	0. 2 3/4	...				
3. 6 5/16	34·8		2	i	1.2 3/16	2. 1 3/16	2	o	1.11 1/4	2. 1 3/16	H. W.	P. v.	P v.	3. 1 3/8	6. 1 5/8	...	0. 2 3/4	...				
6.11 7/8	48·5		2	i	1.4 3/4	2. 0	2	o	2. 1 5/8	2. 2 3/8	H. W.	P. v.	P. v.	3. 1 3/8	6. 1 5/8	3.11 1/2	0. 2 3/4	0.2 5/16				
5. 3	37·7		2	(1) (2)	1.2 3/16	2. 1 5/8	2	(3) (4)	1.11 1/4	2. 1 5/8	H. W.	P. v.	P. v.	3. 1 3/8	6. 0 13/16	4. 0 1/16	...	...				
3. 6 15/16	28 0		2	i	1.7 11/16	1.11 5/8	...	...	...	...	H. W.	P. v.	...	3. 2 3/16	6. 2	3 6 15/16	0. 2 3/16	...				
...	...		2	o	...	2. 0 3/8	...	..	...	...	H. W.	P. v. s.	...	3. 2 3/16	5. 8 15/16	...	...	...				
3. 4 3/16	30.04		2	o	1.7 1/16	2. 2 13/16	...	...	...	...	...	...	...	...	6.10 11/16	...	0. 1 3/16	...				
3. 4 3/16	30·04		1	o	1 7 11/16	2. 2 13/16	1	o	2. 5 1/4	2. 2 13/16	...	...	...	...	6.10 11/16	...	0. 1 3/16	...				
6. 2 3/4	42·0		2	i	1.2 3/16	2. 2	2	o	2. 0 3/8	2. 2	H. W.	P. v.	P. v.	...	6.10 11/16	...	0. 1 3/16	...				

Abbreviations :

. 20) to inside left.
. 20) to outside left.
. 24) to inside right.
. 24) to outside ight.

H. W. (col. 27). = Heusinger-Waldeck motion (Walschaert).
P. v. (col. 28, 29) = Piston valve with spring rings.
P. v. s. (col. 28) = Piston valve with solid rings.

Appendix 2 (*continuation*). **Group 2.**

	COUNTRY.	Index number.	RAILWAY.	DESIGN.	Number of illustration.	Weight. Empty, in lb.	Weight. In working order, in lb. L	Weight. Adhesive, in lb. L_1	Ratio of capacity of cylinders.	Piston speed. At 100 kilometres (62 miles) per hour, in feet and inches per second.	Piston speed. At the maximum speed. Maximum speed, in miles per hour.	Piston speed. At the maximum speed. Piston speed, in feet and inches per second.
1	2	3	4	5	6	35	36	37	38	39	40	41
α	*Denmark* . .	1	Danish State Railway.	2 B 1 4-cylinder compound.	1-5 10	136,000	150,000	73,000	1 : 2·81	17. 7 1/16	...	...
β	*Germany* . .	1	Bavarian State Railw.	2 B 1 4-cylinder compound.	11	137,000	150,500	70,600	1 : 2·81	18. 6 13/16	62·0	18. 6 13/16
γ	— .	1	— — —	2 B 2 4-cylinder superheated-steam compound.	12	166,500	184,440	70,600	1 : 2·21	16.10 3/8	62·0	16.10 3/8
δ	— .	1	— — —	2 C 4-cylinder compound.	13	140,400	153,500	102,500	1 : 2·81	19.10 5/8	62·0	19.10 5/8
ε	— .	1	— — —	2 C 4-cylinder superheated-steam compound.	13	143,000	156,500	103,500	1 : 2·68	19.10 5/8	62·0	19.10 5/8
ζ	— .	1	— — —	2 C 1 4-cylinder superheated-steam compound.	14	173,300	190,600	105,800	1 : 2·34	HP: 18.11 9/16 LP: 20. 9 5/8	62·0	HP: 18.11 9/16 LP: 20. 9 5/8
η	*Italy* . . .	1	Italian State Railway.	1 C 1 4-cylinder compound.	15-19	138,400	154,000	99,200	1 : 2·68	20. 4 7/8	59·0	19. 5 1/16
θ	*Sweden*. . .	1	Swedish State Railw.	2 B 1 2-cyl. superh.-steam.	20	120,500	132,600	68,000	...	18. 6 1/16	55·9	16. 8
ι	— . .	1	— — —	2 C 2-cyl. superh.-steam.	21	...	...	...	...	20. 6 1/2	55·9	18. 6 1/16
κ	*Hungary* . .	1	Hungarian State Railw.	2 B 1 2-cylinder.	...	126,000	141,000	88,300	...	16.10	62·0	16.10
λ	— . .	1	— — —	2 B 1 2-cylinder compound.	...	127,000	143,000	68,500	1 : 2·25	16.10	62·0	16.10
μ	— . .	1	— — —	2 B 1 4-cylinder compound.	26	148,000	164,500	70,000	1 : 2·96	16.10	62·0	16 10

Abbreviations !

H P (column 39, 41) . . . . . = high pressure.

L P (column 39, 41) . . . . . = low pressure.

OMOTIVE (*continuation*).											TENDER.						
ber of revolutions per minute.					Heating surface per ton of weight, in working order, in square feet.	Ratio of heating surface to grate area.	Engine				Number of illustration.	Number of axles.	Stores.			Weight.	
wheels	Carrying wheels													Fuel.			
at the maximum speed (column 40).	leading		trailing				calculated from the cylinders, in lb.	per square foot of heating surface, in lb.	per ton of weight, in working order in lb.	per ton of adhesive weight, in lb.			Water, in gallons.	Solid (coal), in lb.	Liquid (oil), in gallons.	Empty, in lb.	Fully equipped and fully loaded, in lb.
	at 100 miles per hour.	at the maximum speed (column 40.)	at 100 miles per hour.	at the maximum speed (column 40).	$\frac{H}{L} = \frac{\text{col.12}}{\text{col.36}}$	$\frac{H}{R} = \frac{\text{col.12}}{\text{col.18}}$	E	$\frac{E}{H} = \frac{\text{col.50}}{\text{col.12}}$	$\frac{E}{L} = \frac{\text{col.50}}{\text{col.36}}$	$\frac{E}{L_1} = \frac{\text{col.50}}{\text{col.37}}$							
43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
...	504	...	504	...	32·8	63·4	12,360	5·62	184·5	380·0	6-10	4	4,630	13,230	...	47,150	106,600
265	560	560	440	440	32·9	62·8	13,980	5·30	208·0	444·0	11	4	4,800	13,230	...	46,700	106,200
241	530	530	530	530	33·0	53·8	14,150	5·21	172·1	449·0	12	4	5,720	17,640	...	45,200	120,100
284	560	560	...	...	32·3	62·8	14,950	6·75	218·0	327·0	13	4	4,800	15,440	...	48,500	110,200
284	560	560	...	...	30·4	61·0	16,410	7·74	235·0	355·0	13	4	4,800	15,440	...	48,200	117,500
284	560	560	440	440	33·9	59·6	20,720	7·19	243·5	439·0	14	4	5,720	16,540	...	48,900	120,700
273	560	532	435	414	34·5	63·0	16,810	7·08	244 0	380·0	...	3	4,400	13,230	...	32,000	89,300
254	546	492	483	435	30·2	63·8	10,540	5·90	178·0	347·0	22-25	3	3,085	11,460	...	29,800	72,400
273	546	492	...	...	...	...	...	...	...	...	22-25	3	4,400	13,230	...	43,000	100,300
252	...	...	...	...	27·3	57·0	10,780	6·17	166·0	346·0	...	3	3,930	19,500	...	37,500	90,000
252	...	...	...	...	26·9	57·0	11,020	6·35	170·0	358·0	...	3	3,930	19,500	...	37,500	90,000
252	...	...	...	...	34·2	62·0	14,600	5·78	193·0	455·0	27	4	4,000	17,600	...	47,000	105,000

Abbreviations :

E (col. 50), calculated for : 1. { 2-cylinder engines / 4-cylinder engines } . . . . . $= \frac{p \cdot d^2 \cdot l^{(1)}}{D}$

2. 2-cylinder compounds and 3-cylinder compounds. . . $= \frac{p \cdot d^2 \cdot l}{2\,D}$

ne case of 4-cylinder non-compounds the value has to be multiplied by 2.

	COUNTRY.	Index number.	RAILWAY.	DESIGN.	Number of illustration.	Boiler: Height of centre line of boiler above rolling surface of rails.	Boiler: Working pressure, in lb. per square inch.	Boiler: Heating surface in contact with hot gases, Fire-box, in square feet.	Boiler: Heating surface in contact with hot gases, Smoke tubes, in square feet.	Boiler: Heating surface in contact with hot gases, Superheater, in square feet.	Boiler: Heating surface in contact with hot gases, Total $a + b + c$, in square feet.	Boiler: Tubes. Diameter of smoke tubes, internal, external, in feet and inches.	Boiler: Tubes. Diameter of superheater tubes, internal, external, in feet and inches.	Boiler: Tubes. Length between tube-plates, in feet and inches.
						ft. in.								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
α	*Belgium* .	1	Belgian State Railway	2 B 2 cylinder.	...	7. 9	170·0	118·7	1,244·00	...	1,362·70	0.1 3/8 / 0.1 0/16	...	11.
α	— . .	1	— — —	2 B 2 cylinder.	...	8. 0 1/8	185·0	131·1	1,244·00	...	1,375·10	0.1 3/4 / 0.1 2/16	...	11.
α	— . .	1	— — —	2 B 2 cyl. superheated-steam	28	8. 0 1/8	185·0	131·5	1,051·00	264·0	1,446·50	0.5 / 0.4 5/8 ; 0.1 3/4 / 0.1 2/16	?	12.
α	— . .	1	— — —	2 B 1 2 cylinder compound.	29	8.10 5/16	220·5	174·1	2,333·00	...	2,507·10	0.2 3/4 S / 0.2 2/16	...	14.
α	— . .	1	— — —	2 C 4 cyl. superheated-steam	30-31	9. 3 1/16	199·1	177·0	1,495·00	407·0	2,079·00	0.5 / 0.4 5/8 ; 0.2 / 0.1 3/4	?	13
β	*Germany* .	1	Baden State Railway.	2 B 2 cylinder.	33-36	7. 6 2/16	185·0	95·1	1,028·00	...	1,123·10	0.2 1/16 / 0.1 13/16	...	12.
β	— .	1	— — —	2 B 1 4 cylinder compound.	37-40	9. 0 1/4	227·6	146·6	2,115·00	...	2,261·60	0.2 1/16 / 0.2 7/8	...	15.
β	— .	1	— — —	2 C 1 4 cylinder superheated-steam compound.	41-44	9. 3 1/16	227·6	158·3	2,090·00	538·0	2,766·20	0.5 7/16 / 0.5 1/16 ; 0.2 8/16 / 0.2	0.1 7/16 / 0.1 1/8	16.
γ	*France* . .	1	Paris-Lyons-Mediterranean Railway.	1 B 4 cylinder compound.	49-50	7. 4 2/16	213·0	107·9	1,486·00	. .	1,593·90	0.2 0 1/16 S / 0.2 8/8	...	9.
γ	— . .	1	Ditto	2 B 2 cylinder.	51-52	6.10 11/16	156·4	107·9	1,414·00	...	1.521·90	0.2 0 1/16 S / 0.2 8/8	...	10.
γ	— . .	1	Ditto	2 B 4 cylinder compound.	53-54	8. 1 1/4	213·0	134·9	1,904·00	...	2,038·90	0.2 0 1/16 S / 0.2 8/8	...	11.
γ	— . .	1	Ditto	2 B 1 2 cylinder.	55-56	8.11 1/4	213·0	169·8	1,745·00	...	1,914·80	0.2 / 0.1 3/4	...	14.
γ	— . .	1	Ditto	2 B 1 4 cylinder compound.	57-58	8. 6 8/16	227·6	166·0	2,213·00	...	2,379·00	0.2 3/4 S / 0.2 2/16	...	13.
γ	— . .	1	Ditto	2 C 4 cylinder compound.	59-60	8. 6 8/16	227·6	166·0	2,213·00	...	2,379·00	0.2 3/4 S / 0.2 2/16	...	13.
γ	— . .	2	French State Railway	2 B 1 4 cylinder compound.	67	8.10 5/16	227·6	174·0	2,400·00	...	2,574·00	0.2 3/4 S / 0.2 2/16	...	14.
γ	— . .	3	Midi Railway . . .	2 B 4 cylinder compound.	68	8. 0 1/2	213·0	136·0	1,750·00	...	1,886·00	0.2 3/4 S / 0.2 2/16	...	12.
γ	— . .	3	— — . . .	2 B 1 4 cylinder compound.	69	8. 4 2/8	227·6	168·5	2,026·50	...	2,190·00	0.2 3/4 S / 0.2 2/16	...	14.
γ	— . .	3	— — . . .	2 C 1 4 cylinder compound.	70	9. 4 2/16	227.6	163·1	2,530·00	...	2,693·10	0.2 1/4 / 0.2 1/16	...	19.
δ	*Gr. Britain*	1	Great Central Railway	2 B 1 3 cylinder compound.	71	8. 6	180·0	153·0	1,778·00	...	1,931·00	0.2 / ...	...	15.

Abbreviations : s (col. 13) = Serve (ribbed tubes). — H. W. (col. 27) = Heusinger-Waldeck motion (Walschaerts). — GM (col. 27) = motion. — St. (col. 27) = Stephenson motion. — A. (col. 27) = Allan motion. — H. P. (col. 27, 39, 41) = High pressure. — L. P. (col. 27, = Low pressure. — Fl. s. (col. 28, 29) = Flat slide valve balanced. — Fl. s. v. (col. 28, 29) = Flat slide valve not balanced. — P. v. (col = Piston valve with spring rings. — P. v. s. col. 28, 29) = Piston valve with solid rings.

LOCOMOTIVE :

Grate.			Engine :											Running gear.				
			Steam cylinders.								Steam distribution,			Diameter of wheels, measured at tread.			Lateral play on each side of centre.	
			High pressure.				Low pressure.					Type of valve.						
	Clear width, in feet and inches.	Useful grate area, in square feet.	Number.	Position {inside (i). outside (o).	Diam., in feet and inches.	Length of stroke, in feet and inches.	Number.	Position {inside (i). outside (o).	Diam., in feet and inches.	Length of stroke, in feet and inches.	Type of motion.	High pressure.	Low pressure.	Leading bogie or leading carrying wheels, in feet and inches.	Driving wheels & coupled wheels, in ft. and inches.	Trailing bogie or trailing carrying wheels, in feet and inches.	Leading bogie or leading carrying wheels, in feet and inches.	Trailing bogie or trailing carrying wheels, in feet and inches.
		R			*d*	*h*			*d*	*h*					D			
	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
9/16	3. 6 1/8	20·65	2	i.	1.7	2. 2	...	...	...	...	...	P. v.	...	3. 6	6. 6	...	0.0 15/16	...
3/4	3. 6 1/8	22·31	2	i.	1.7	2. 2	...	...	...	...	...	P. v.	...	3. 6	6. 6	...	0.0 15/16	..
3/4	3. 6 1/8	22·31	2	i.	1.7 1/4	2. 2	...	...	...	...	St.	P. v.	...	2.11 7/16	6. 6	...	0.2 3/16	...
1/4	3. 4 1/8	33·15	1	o.	1.2 1/8	2. 1 3/16	1	o.	1.11 5/8	2.1 3/16	H.W.	P. v.	P. v.	2.11 7/16	6. 6	4. 7 7/8	0.2 3/16	D
3/4	3. 4 7/8	34·24	4	2o. 2i.	1.5 11/16	2. 1 3/16	...	...	...	...	H. W.	P. v.	...	2.11 7/16	6. 6	...	0.2 3/16	...
7/16	3. 3 3/8	22·19	2	i.	1 6 1/8	1.11 5/8	...	...	...	...	H W.	Fl. s.	...	3. 3	6.10 11/16	...	0.1 3/16	...
7/16	6. 2 5/8	41·65	2	i.	1.1 3/16	2. 0 3/8	2	o.	1.10 7/16	2.0 3/8	H.W.	P. v.	P. v.	3. 3	6.10 11/16	3.11 1/4	0.2 9/16	0.0 13/16
7/16	6.11 1/16	48·45	2	i.	1.4 3/4	2. 0	2	o.	2. 1 5/8	2.2 3/8	H.W.	P. v.	P. v.	3. 3	5.10 7/8	3.11 1/4	0.2 15/16	0.2 7/16
9/16	3. 4 5/16	25·63	2	o.	1. 1 3/8	2. 0 3/8	2	i.	1. 9 1/4	2.0 3/8	H. P. H.W. L. P. G M.	Fl. s. v.	Fl. v.	4. 3 5/16	6. 6 3/4	...	0.0 5/8	...
1/4	3. 3 3/4	25·00	2	o.	1.7 1/4	2. 0 3/8	...	...	...	...	A.	Fl. s. v.	...	3. 3 3/8	6. 6 3/4	...	0.0 5/8	...
1/16	3. 4 1/4	26·70	2	o.	1.1 3/8	2. 0 3/8	2	i.	1. 9 1/4	2.0 3/8	H.P. H.W. L. P. G M.	Fl. s. v.	Fl. s. v.	3. 3 3/8	6. 6 3/4	...	0.0 5/8	...
5/16	3. 6	35·00	2	o.	1.5 1/4	2. 2	...	...	...	...	St.	P. v.	...	2.11 7/16	6.11 1/2	4. 5 1/2	0.3 11/16	...
9/16	3. 4 1/4	32·10	2	o.	1.1 3/8	2. 1 9/16	2	i.	1. 9 1/4	2.0 3/8	H.P. H.W. L.P. H.W.	P. v.	P v.	3. 3 3/8	6. 6 3/4	4.11 1/16	0.1 3/8	... Back coupled axle 0.0 5/16
9/16	4. 4 1/4	32.10	2	o.	1.1 3/8	2 1 9/16	2	i.	1. 9 1/4	2.0 3/8	H.P. H.W. L.P. H.W.	P. v.	P. v.	3. 3 3/8	6. 6 3/4	...	0.1 3/8	
1/16	3. 3 3/8	33·40	2	o.	1.2 9/16	2. 1 3/16	2	i.	1.11 5/8	2.1 9/16	...	Fl. s.	Fl. s. v.	3. 3 5/16	6. 6 3/8	4.10 5/16	0.1 3/4	...
9/16	3. 2 7/8	31·70	2	o.	1.1 13/16	2. 1 9/16	2	i.	1. 9 11/16	2.1 5/16	H.W.	Fl. s. v.	Fl. s. v.	..	...	...	0.1	...
5/8	3. 3	33·20	2	o.	1.1 3/8	2. 1 3/16	2	i.	1.10 1/16	2.1 3/16	H.W.	—	—	...	...	...	0.1 3/4	D
5/16	3. 2 6. 1 1/4	44·00	2	o.	1.2 9/16	2. 1 9/16	2	i.	2. 0 3/8	2.1 9/16	H. W	Fl. s.	Fl. s.	...	...	...	0.1 1/4	0.1 3/16
3/8	3. 4	26.20	1	i.	1.7	2. 2	2	o.	1. 9	2.2	St.	Fl. s.	...	3. 6	6. 9	4. 3	0.0 9/16	0.0 7/16

$_1$ (for non-compounds) = 0·5 p (col. 8)

$_1$ (— for compounds) = α . p (col. 8)

Ratio of capacity of cylinders	1 : 2·0	1 : 2·25	1 : 2·5	1 : 3·0
α	0·44	0·42	0·40	0·37

	COUNTRY.	Index number.	RAILWAY.	DESIGN.	Number of illustration.	Weight.			Ratio of capacity of cylinders.	Piston speed.		
						Empty, in lb.	In working order, in lb.	Adhesive, in lb.		At 100 kilometres (62 miles) per hour, in feet and inches per second.	At the maxi speed.	
							L	L_1			Maximum speed miles per hour.	Piston speed, in feet and inches
1	2	3	4	5	6	35	36	37	38	39	40	4
α	*Belgium* . .	1	Belgian State Railway	2 B 2 cylinder.	...	105,200	115,600	77,200	...	19. 4 5/16	68.3	21. 3
α	— . .	1	— — —	2 B 2 cylinder.	...	107,500	117,500	80,200	...	19. 4 5/16	68.3	21. 3
α	— . .	1	— — —	2 B 2 cyl.superheated-steam	28	119,000	129,800	81,400	...	19. 4 5/16	68.3	21. 3
α	— . .	1	— — —	2 B 1 2 cylinder compound.	29	150,000	164,200	81,400	1 : 2·78	18. 9 3/16	68.3	20. 7
α	— . .	1	— — —	2 C 4 cyl.superheated-steam	30-31	163,100	182,500	119,400	...	18. 9 3/16	68.3	20. 7
β	*Germany* . .	1	Baden State Railway.	2 B 2 cylinder.	33-36	93,600	102,600	67,300	...	16. 7 3/16	68.3	18. 2
β	— . .	1	— — —	2 B 1 4 cylinder compound.	37-40	150,000	165,400	72,600	1 : 2·90	17. 2 5/16	68.3	18.1
β	— . .	1	— — —	2 C 1 4 cylinder superheated-steam compound.	41-44	78,600	195,000	108,400	1 : 2·57	H.P.: 16.8 12/16 L.P.: 18.4 1/2	68.3	H.P. : L P. :
γ	*France* . .	1	Paris-Lyons-Mediterranean Railway.	1 B 4 cylinder compound.	49-50	94,600	101,600	69,200	1 : 2·52	17.11 3/4	...	
γ	— . .	1	Ditto	2 B 2 cylinder.	51-52	102,800	110,100	68,190	...	17.11 3/4	...	
γ	— . .	1	Ditto	2 B 4 cylinder compoun l.	53-54	115,400	124,300	75,800	1 : 2·52	17.11 3/4	...	
γ	— . .	1	Ditto	2 B 1 2 cylinder.	55-56	130,900	143,500	78,400	...	18. 0 9/16	...	
γ	— . .	1	Ditto	2 B 1 4 cylinder compound.	57-58	140,000	151,500	79,200	1 : 2·41	H.P.: 18.10 L.P.: 17.4 3/4	...	
γ	— . .	1	Ditto	2 C 4 cylinder compound.	59-60	144,400	155,900	110,100	1 : 2·41	H.P.: 18.10 L.P.: 17.11 3/4	...	
γ	— . .	2	French State Railway	2 B 1 4 cylinder compound.	67	146,500	160,800	78,750	1 : 2·78	18. 6 13/16	68 3	20.
γ	— . .	3	Midi Railway . . .	2 B 4 cylinder compound.	68	113,800	123,800	75,250	1 : 2·47	...	69.5	
γ	— . .	3	— — . . .	2 B 1 4 cylinder compound.	69	138,000	153,000	77,300	1 : 2·71	...	69 5	
γ	— . .	3	— — . . .	2 C 1 4 cylinder compound.	70	177,500	199,500	119,100	1 : 2·80	...	69.5	
δ	*Great Britain.*	1	Great Central Railway	2 B 1 3 cylinder compound.	71	115,700	159,600	82,880	1 : 2·66	18. 7 5/8	...	

E (column 50) calculated for : 1. { 2 cylinder engines / 4 cylinder engines } . . . . . $= \frac{p \cdot d^2 \cdot l\,(1)}{D}$

2. 2 cylinder compounds and 3 cylinder compounds . . . $= \frac{p \cdot d^2 \cdot l}{2\,D}$

(1) In the case of four-cylinder non-compounds the value has to be multiplied by 2.

COMOTIVE (*continuation*).												TENDER						
umber of revolutions per minute.							Engine							Stores.			Weight.	
ng wheels	Carrying wheels				Heating surface per ton of weight, in working order, in square feet.	Ratio of heating surface to grate area.									Fuel.			
	leading		trailing				calculated from the cylinders, in lb.	per square foot of heating surface, in lb.	per ton of weight, in working order, in lb.	per ton of adhesive weight, in lb.							
at the maximum speed (Column 40.)	at 100 miles per hour.	at the maximum speed (Column 40.)	at 100 miles per hour.	at the maximum speed (column 40).	$\frac{H}{L}=\frac{\text{col.12}}{\text{col.36}}$	$\frac{H}{R}=\frac{\text{col.12}}{\text{col.18}}$	E	$\frac{E}{H}=\frac{\text{col.50}}{\text{col.12}}$	$\frac{E}{L}=\frac{\text{col.50}}{\text{col 36}}$	$\frac{E}{L_1}=\frac{\text{col.50}}{\text{col.37}}$	Number of illustration.	Number of axles.	Water, in gallons.	Solid (coal), in lb.	Liquid (oil), in gallons.	Empty, in lb.	Fully equipped and fully loaded, in lb.
43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
295	498	549	...	...	26·4	66·0	10,300	7·55	199·5	299	...	3	4,400	13,230	...	48,300	105,500
295	498	549	...	...	26·2	61·6	11,140	8·11	212·2	312	...	3	4,400	13,230	...	48,300	105,500
295	590	648	...	...	25·0	64·8	11,950	8·26	206·4	329	32	3	4,400	13,230	...	48,300	105,500
295	590	648	374	411	34·2	75·6	7,560	3·02	103·2	208	32	3	4,400	13,230	...	48,300	105,500
295	590	648	...	...	25·5	65·4	19,750	9·50	242·7	371	32	3	4,400	13,230	...	48,300	105,500
278	536	590	...	...	24·5	50·6	8,660	7·71	189·0	288	...	4	3,350	11,030	...	41,600	86,200
278	536	590	442	487	30·6	54·4	12,790	5·57	173·2	395	45-46	4	4,400	13,230	...	49,600	107,000
324	536	590	442	487	32·0	57·5	21,910	7·88	252·0	453	47-48	4	4,400	15,440	...	50,350	108,000
...	409	..	...	...	35·1	62·2	11,950	7·50	263·5	387	61-63	4	4,300	6,620	...	45,500 38,200	96,200 83,600
...	531	...	...	...	31·0	61·0	9,420	6·19	191·5	310	...	3	3,545	8,820	...	38,700	84,100
...	531	...	...	...	36·7	76·4	11,950	5·87	215·0	353	64-66	3	4,430	7,720	...	43,400	98,000
...	585	...	390	...	29·9	54·8	9,880	5·16	154·1	301	...	3	3,745	8,820	...	36,900	84,200
...	531	...	354	...	35·2	74·2	13,050	5·50	193·0	394	64-66	3	4,430	8,820	...	43,500	98,000
...	531	...	...	...	34·2	74·2	13,050	5·50	187·5	265	64-66	3	4,430 4,650	8,820	...	43,500 43,380	98,000 100,200
292	531	584	359	394	35·4	77·0	15,450	6·00	215·6	442	67 R.s.	3	4,400	13,230	...	43,000	101,400
	...	...	...	...	33·5	70·0	...	...	...	...	68	3	3,480	8,820	..	33,500	77,800
	...	...	...	...	31·9	66·0	...	...	...	...	...	3	3,480	11,030	...	34,800	81,300
	...	...	...	...							69	4	4,400	11,030	...	44,200	100,000
	...	...	...	...	29·8	61·0	...	...	...	...	70	3	4,400	11,030	...	41,300	97,000
...	496	...	410	...	26·5	74·0	9,920	5·16	138·9	268	71	3	4,000	11,200	...	52,176	103,376

(col. 54) = Ramsbottom scoop.

	COUNTRY.	Index number.	RAILWAY.	DESIGN.	Number of illustration.	Boiler: Height of centre line of boiler above rolling surface of rails.	Working pressure, in lb. per square inch.	Heating surface in contact with hot gases. Fire-box, in square feet.	Smoke tubes, in square feet.	Superheater, in square feet.	Total $a + b + c$, in square feet.	Tubes. Diameter of smoke tubes, internal, external, in feet and inches.	Diameter of superheater tubes internal, external, in feet and inches.	Length between tube
						ft. in.								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
α	*France* . .	1	French Eastern Rail w.	2 C 4-cylinder compound.	72-73	S. 9 7/8	227·5	174·50	2,354·00	...	2,528 50	0.2 3/4 / 0.2 1/2	...	14
α	— . . .	2	French North. Railw.	2 B 2-cylinder.	77-78	6. 11 3/4	142·2	100·60	906 00	...	1,006·60	... / 0.1 3/4	...	4
						6. 11 3/4	156·5	100·60	1,365·00	...	1,465 60	... / 0.2 3/4 S	...	4
α	— . . .	2	— — —	2 B 4-cylinder compound.	79-80	7. 4 9/10	213·0	114·50	1,490·00	...	1,604·50	... / 0.2 3/4 S	...	12
α	— . . .	2	— — —	2 B 4-cylinder compound.	...	S. 0 1/2	213·0	129 40	1,663·00	...	1,792·40	... / 0.2 3/4 S	...	12
α	— . . .	2	— — —	2 B 1 4-cylinder compound.	81	S. 3 3/16	227·5	169·40	2,200 00	...	2,369·40	... / 0.2 3/4 S	...	14
α	— . . .	2	— — —	2 B 1 4-cylinder compound.	...	S. 3 3/16	227·5	169·50	2,150·00	...	2,319·50	... / 0.2 3/4 S	...	13
α	— . . .	2	— — —	2 C 4-cylinder compound.	...	7. 11 1/4	213·0	126 70	1,783·00	...	1,909·70	... / 0.2 3/4 S	...	13
α	— . . .	2	— — —	2 C 4-cylinder compound.	...	7. 11 1/4	213·0	126·70	1,765·00	...	1,891·70	... / 0.2 3/4 S	...	13
α	— . . .	2	— — —	2 C 4-cylinder compound.	82-84	S. 7 9/16	227 5	169 40	2,200 00	...	2,369 40	... / 0.2 3/4 S	...	14
α	— . . .	3	Orleans Railway . .	2 B 4-cylinder compound.	85-86	S. 0 1/2	213·0	130·00	1,920·00	...	2,050·00	0.2 3/4 S / 0.2 5/16	...	12
α	— . . .	3	— — . .	2 B 1 4-cylinder compound.	87-88	S. 10 5/16	227.5	174·00	2,450·00	...	2,579·00	0.2 3/4 S / 0.2 5/16	...	14
α	— . . .	3	— — . .	2 C 4-cylinder compound.	89-90	S. 10 5/16	227·5	174 00	2,450·00	...	2,579·00	0.2 3/4 S / 0.2 5/16	...	14
α	— . . .	3	— — . .	2 C 1 4-cylinder compound.	91-92	9. 3 1/4	227·5	165·50	2,600·00	...	2,765·50	0.2 3/16 / 0.2	...	19
β	*Gr. Britain*	1	Caledonian Railway .	2 B 2-cylinder.	...	7. 9	160 0	118·78	1,284 00	...	1,402·78	0.1 3/4 / ...	...	10
β	—	1	— — — .	2 B 2-cylinder.	93	S. 3	180 0	145·00	1,470·00	...	1,615·00	0.1 3/4 / ...	...	1
β	—	1	— — — .	2 C 2-cylinder.	94	S. 6	200·0	148·25	2,112·00	...	2,260 25	0 2 / ...	...	1
β	—	2	Great Eas'ern Railway	2 B 2 cylinder.	95	S. 5	180·0	117·70	1,589·00	...	1,706·70	0.1 3/4 / 0.1 3/16	...	1
β	—	3	Great Western Railway	2 B 1 2-cylinder tank locomotive.	96	S. 6	195·0	121·31	1,396·58	...	1,517·89	0.1 3/8 / ...	...	1
β	—	3	— — —	2 C 4-cylinder superheated-steam.	97	S. 6	225 0	154·5	1,658 00	269 00	2,081·5	0.2 / 0.1 3/4	0·4 3/4 / 0·4 3/8	1
β	—	4	Lancashire & Yorkshire Railway.	2 B 2-cylinder.	98	7. 9	180·0	107·68	1,109·00	...	1,216·68	0.1 3/4 / 0.1 1/2	...	1
β	—	4	Ditto	2 B 1 2-cylinder.	99	S. 11	180·0	175·60	1,877 00	...	2,052·60	0.2 / 0.1 3/4	...	1
β	—	5	Midland Railway . .	2 B 3-cylinder compound.	100	S. 6	220·0	152·80	1,306·00	...	1,458·80	0.1 3/8 / ...	...	1
β	—	5	— — . .	2 B 2-cylinder.	...	S. 6	180·0	145·00	1,311·00	...	1,456.00	0.1 3/4 / ...	...	
β	—	6	North Eastern Railway	2 B 2 cylinder.	101	S. 4	180 0	144·00	1,383·00	...	1,527·00	0.1 3/4 / 0.1 1/2	...	
β	—	7	South Eastern & Cha-tham Railway.	2 B 2-cylinder.	102	S. 0	180·0	136·00	1,297·00	...	1,423·00	0.1 3/4 / 0.1 1/2	...	

Abbreviations : p_1 (for non-compounds) $= 0{\cdot}5\ p$ (col. 8),

p_1 (for compounds) $= \alpha \cdot p$ (col. 8).

Ratio of capacity of cylinders . .	1 : 2·0	1 : 2·25	1 : 2·5
α	0·44	0·42	0·40

LOCOMOTIVE.

Grate.		Engine.										Running gear.				
		Steam cylinders.								Steam distribution.		Diameter of wheels, measured at tread.			Lateral play on each side of centre.	
		High pressure.				Low pressure.					Type of valve.					
Clear length, in feet and inches.	Useful grate area, in square feet.	Number.	Position { inside if outside o.	Diameter, in ft. and inches.	Length of stroke in feet and inches.	Number.	Position { inside if outside o.	Diameter, in ft. and inches.	Length of stroke, in feet and inches.	Type of motion.	High pressure.	Leading bogie or trailing carrying wheels, in feet and inches.	Driving wheels and coupled wheels, in feet and inches.	Trailing bogie or trailing carrying wheels in feet and inches.	Leading bogie or trailing carrying wheels, in feet and inches.	Trailing bogie or trailing carrying wheels, in feet and inches.
R				*d*	*h*			*d*	*h*				D			
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
3. 3 9/16	34·02	2	o	1.2 3/16	2.2 13/16	2	i	1.11 1/4	2.2 13/16	H. W.	P. v.	P. v.	3. 1 1/4	6.10 1/4	...	0.2 3/16	...
3. 4 3/16	25·90	2	i	1.5 11/16	2.0	...	..	...	...	St.	Fl. s. v.	..	3. 3 3/4	6.10 11/16	...	0.0 7/8	...
3. 4 3/16	25·90	2	i	1.6 1/8	2.0	...	...	...	...	St.	Fl. s. v.	...	3. 4 15/16	6.11 1/4	...	0.0 7/8	...
3. 2 3/16	21·20	2	o	1.1 3/8	2.1 3/16	2	i	1.8 7/8	2.1 3/16	...	Fl. s. v.	Fl. s. v.	3. 4 15/16	6.11 7/8	...	0.0 7/8	...
3. 2 5/8	25·90	2	o	1.1 3/8	2.1 3/16	2	i	1.8 7/8	2.1 3/16	...	Fl. s. v.	Fl. s. v.	3. 4 15/16	6.11 7/8	...	0.0 7/8	...
3. 3	29·70	2	o	1.1 3/8	2.1 3/16	2	i	1.10 1/16	2.1 3/16	...	Fl. s.	Fl. s. v.	2.11 1/16	6. 8 5/16	4. 7 15/16	0.1 3/4	...
3. 3	29·70	2	o	1.1 3/8	2.1 3/16	2	i	1.10 1/16	2.1 3/16	...	Fl. s.	Fl. s. v.	2.11 1/16	6. 8 5/16	4. 7 15/16	0.1 3/4	...
3. 2 7/8	25·60	2	o	1.1 13/16	2.1 3/16	2	i	1.9 13/16	2.1 3/16	...	Fl. s. v.	Fl. s. v.	2. 9 1/2	5. 8 7/8	...	0.1	...
3. 2 7/8	25·60	2	o	1.1 13/16	2.1 3/16	2	i	1.9 11/16	2.1 3/16	...	Fl. s. v.	Fl. s. v.	2. 9 1/2	5. 8 7/8	...	0.1	...
3. 3	29·70	2	o	1.1 13/16	2.1 3/16	2	i	1.9 11/16	2.1 3/16	...	Fl. s.	Fl. s.	2.11 1/16	5. 8 7/8	...	0.1 3/4	..
3. 3 7/8	26·50	2	o	1.1 13/16	2.1 3/16	2	i	1.9 13/16	2.1 3/16	H. W.	...	...	3. 3 3/8	6.10 1/4	...	0.2	...
3. 3 3/8	33·40	2	o	1.2 3/16	2.1 3/16	2	i	1.11 5/8	2.1 3/16	H. W.	...	...	3. 0 1/4	6. 6 3/4	4.11 1/16	0.1 3/4	C
3. 3 3/8	33·40	2	o	1.2 3/16	2.1 3/16	2	i	1.11 5/8	2.1 3/16	H. W.	...	...	3. 0 1/4	5.10 7/8	...	0.1 3/4	...
6. 2 and 3. 2 3/4	46·00	2	o	1.3 3/8	2.1 3/16	2	i	2. 1 3/16	2.1 3/16	H. W.	...	...	3. 0 1/4	5.10 7/8	3. 7 5/16	0.1 5/4	0.1 3/4
3. 5	20·6	2	i	1.6 1/4	2.2	...	...	...	...	...	...	...	3. 6	6. 6	...	0.0 3/4	...
3. 3 1/2	21·0	2	i	1.7	2.2	...	...	...	...	...	...	...	3. 6	6. 6	...	0.0 3/4	...
3. 3 1/2	26·0	2	i	1.8	2.2	...	...	...	...	...	...	...	3. 6	6. 6	...	0.0 3/4	...
3. 3 1/8	21·6	2	i	1.7	2.2	...	..	...	...	...	Fl. s. v.	Fl. s. v.	3. 9	7. 0	...	0.1 1/2	...
...	20·35	2	o	1.6	2.6	...	...	...	...	...	...	...	3. 2	6. 8 1/2	3. 8	...	...
3. 2 5/8	27·10	4	21/20	1.2 1/4	2.2	...	...	...	...	H. W.	P. v.	P. v.	3. 2	6. 8 3/2	...	0.4	...
3. 6	18·83	2	i	1.6	2.2	...	...	...	...	...	Fl. s. v.	Fl. s. v.	3. 0 1/2	7. 3	...	0.1 1/4	...
3. 3 1/16	22·97	2	i	1.7	2.2	...	...	...	...	...	Fl. s.	Fl. s.	3. 0 1/2	7. 3	3. 7 5/8	0.2	0.1
3. 4 1/4	28.40	1	i	1.7	2.2	2	o	1.9	2·2	...	Fl. s. v.	Fl. s. v.	3. 6 1/2	7. 0	...	0.1 3/4	Driving and coupled axles, 0.0 1/8
3. 4 1/4	25·00	2	i	1.7 1/2	2.2	...	...	...	...	...	...	...	3. 3 1/2	6. 9	....	0.1 5/8	Driving and coupled axles. 0.0 1/8
3. 2 1/2	20·48	2	i	1.7	2.2	...	...	...	...	St.	P.	P.	4. 0	6.10	....	0.1 1/2	...
3. 4 3/8	21·15	2	i	1.7 1/4	2.2	...	...	...	...	...	Fl. s. v.	Fl. s. v.	3. 6	6. 6	...	0.1 1/4	Driving axle. 0. 1/16

Abbreviations :

27) = Heusinger-Waldeck motion (Walschaerts).

28-29) = Piston valve with spring rings.

P. v. s. (col. 28) = Piston valve, with solid rings.

	COUNTRY.	Index number.	RAILWAY.	DESIGN.	Number of illustration.	Weight. Empty, in lb.	Weight. In workings order, in lb. L	Weight. Adhesive, in lb. L_1	Ratio of capacity of cylinders.	Piston speed. At 100 kilometres (62 miles) per hour, in feet and inches per second.	Piston speed. At t speed max. Maximum speed, in lb. per hour.	
1	2	3	4	5	6	35	36	37	38	39	40	
α	*France* . .	1	French Eastern Railway.	2 C 4-cylinder compound.	72-73	154,894	169,288	117,374	1 : 2·68	18.10 3/8	75·0	25
											75·0	20
α	— . .	2	French Northern Railway	2 B 2-cylinder.	77-78	87,800 87,800	94,800 94,800	63,000 63,000	... ...	16.10 16. 8 13/16	75·0	26
α	— . .	2	— — —	2 B 4-cylinder compound.	79-80	99,800	102,800	67,500	1 : 2·43	17. 5 1/16	75·0	20
α	— . .	2	— — —	2 B 4-cylinder compound.	...	106,000	115,500	71,400	1 : 2·43	17. 5 1/16	75 0	20
α	— . .	2	— — —	2 B 1 4-cylinder compound.	81	135,660	148,600	73,000	1 : 2·71	18. 2 1/8	75·0	21
α	— . .	2	— — —	2 B 1 4-cylinder compound.	...	130,300	142,000	71,200	1 : 2·71	18. 2 1/8	75·0	21
α	— . .	2	— — —	2 C 4-cylinder compound.	...	119,000	129,000	93,600	1 : 2·47	21. 2 11/16	75·0	25
α	— . .	2	— — —	2 C 4-cylinder compound.	...	123.500	136,000	98,100	1 : 2·47	21. 2 11/16	75·0	25
α	— . .	2	— — —	2 C 4-cylinder compound.	82-84	136,000	148,800	105,800	1 : 2·47	21. 2 11/16	75·0	25
α	— . .	3	Orleans Railway . . .	2 B 4-cylinder compound.	85-86	112,800	121,250	73,800	1 : 2·47	17. 9 3/8	75·0	21
α	— . .	3	— . . .	2 B 1 4-cylinder compound.	87-88	150,000	163,000	79,400	1 . 2·78	18. 6 13/16	75·0	23
α	— . .	3	— . . .	2 C 4-cylinder compound.	89-90	152,700	166,700	120,400	1 : 2 78	20. 8 1/16	75·0	24
α	— . .	3	— . . .	2 C 1 4-cylinder compound.	91-92	179,250	198,500	115,250	1 : 2·7	21. 0	75·0	25
β	*Great Britain.*	1	Caledonian Railway . .	2 B 2-cylinder.	. .	122,256	105,252	70,000	...	19. 4 5/16	70·0	27
β	— .	1	— — . .	2 B 2-cylinder.	93	118,720	121,800	80,476	...	19. 4 5/16	70·0	27
β	— .	1	— — . .	2 C 2-cylinder.	94	159,040	163,520	122,080	...	19. 4 5/16	70·0	27
β	— .	2	Great Eastern Railway. .	2 B 2-cylinder.	95	107,128	115,808	77,140	...	17.11 3/4	70·0	26
β	— .	3	Great Western Railway .	2 B I 2-cyl. tank locomotive.	96	133,280	168,000	82,880	...	23. 8 1/4	80·0	36
β	— .	3	— — — .	2 C 4-cylinder superheated-steam.	99	147,840	161,280	122,750	...	18. 9 9/16	80·0	24
β	— .	4	Lancashire & Yorkshire Railway.	2 B 2-cylinder.	98	92,512	100,352	69,440	...	17. 3 7/8	77·0	23
β	— .	4	Ditto	2 B 1 2-cylinder.	99	118,300	131,600	78,400	...	17. 3 7/8	77·0	23
β	— .	5	Midland Railway . . .	2 B 3-cylinder compound.	100	124,124	133,952	87,584	1 : 2·66	17.11 3/4	...	
β	— .	5	— — . . .	2 B 2-cylinder.	...	109,760	120,848	80,416	...	18. 7 5/16	...	
β	— .	6	North Eastern Railway .	2 B 2-cylinder.	101	109,676	115,808	78,960	...	18. 5 1/4	75·6	23
β	— .	7	South Eastern & Chatham Railway.	2 B 2-cylinder.	102	108,080	117,040	78,176	...	19. 4 5/16	70·0	27

Abbreviations : E (col. 50) calculated for : 1° { Two-cylinder engines. / Four-cylinder engines. } . . . . . $= \frac{p \cdot d^2 \cdot l}{D}$ (1)

(1) In the case of four-cylinder non-compounds the value has to be multiplied by 2.

OTIVE (*continuation*).

of revolutions per minute.					Heating surface per ton of weight, in working order, in square feet.	Ratio of heating surface to grate area.	Engine				TENDER.						
els	Carrying wheels						calculated from the cylinders, in lb.	per square foot of heating surface, in lb.	per ton of weight, in working order, in lb.	per ton of adhesive weight, in lb.	Number of illustration.	Number of axles.	Stores.			Weight.	
	leading		trailing										Water, in gallons.	Fuel		Empty, in lb.	Fully equipped and fully loaded, in lb.
	at 100 miles per hour.	at the maximum speed (column 40).	at 100 miles per hour.	at the maximum speed (column 40).	$\frac{H}{L} = \frac{\text{col.12}}{\text{col.36}}$	$\frac{H}{R} = \frac{\text{col.12}}{\text{col.18}}$	E	$\frac{E}{H} = \frac{\text{col.50}}{\text{col.12}}$	$\frac{E}{L} = \frac{\text{col.50}}{\text{col.36}}$	$\frac{E}{L_1} = \frac{\text{col.50}}{\text{col.37}}$				Solid (coal), in lb.	Liquid (oil), in gallons.		
3	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
94	576	692	...	...	33·5	74	15,580	6·17	206·0	298	74-76	3	4,885	13,230	...	44,026	106,732
03	526	631	...	...	25·2	41	6,480	6·07	153·0	229	...	2	3,130	7,720	...	33,700	73,000
01	510	612	...	...	35·3	57	7,410	5·06	175·0	262	...	3	3,130	7,720	...	33,700	73,000
99	510	612	...	...	33·3	76	11,440	7·14	237·0	378	...	3	3,470	8,120	...	34,850	78,000
99	510	612	...	...	35·3	70	11,440	6·28	222·0	359	...	4	3,990	11,030	...	44,200	95,700
12	590	707	374	499	35·7	56	13,550	5·73	204·0	416	81	3	4,230	8,830	...	40,550	92,200
12	590	707	374	499	35·7	78	13,560	5·84	212·0	427	...	4	4,400	11,030	...	44,650	100,300
34	624	750	...	...	33·1	75	14,650	7·68	254·0	350	...	3	3,350	8,820	...	35,050	77,900
34	624	750	...	...	31·2	74	14,650	7·75	241·0	334	...	3	3,350	8,820	...	37,750	80,600
34	590	707	...	...	35·7	80	15,600	6·59	235·0	330	82,84	3	5,060	13,230	...	41,200	106,000
04	530	636	...	...	37·9	77	12,250	5·98	226·0	371	85, 86	3	3,750	7,740 9,260	... ...	40,150	85,600 86,900
18	576	692	354	425	35·3	77	15,450	6·00	212·0	437	87, 88	3	4,400	13,230	...	44,000	101,300
54	576	692	...	..	35·3	77	17,160	6·66	232·0	320	89, 90	3	3,750 4,400	9,260 13,230	... ...	40,050 44,000	86,800 101,300
54	576	692	482	578	31·2	60	20,350	7·36	230·0	396	91, 92	3	4,400	13,230	...	44,000	101,300
03	498	562	...	...	30·0	69	8,820	6·28	181·5	272	...	3	3,570	10,080	...	41,748	87,528
03	498	562	...	...	30·0	77	7,330	4·52	130·6	198	93	4	4,300	10,080	...	65,640	118,720
03	498	562	...	...	31·2	88	13,240	5·85	176·0	237	94	4	5,000	11,200	...	66,480	127,680
81	464	524	...	...	45·6	79	10,800	6·32	142·0	303	95	3	3,450	11,200 3,360	... 715	43,232	87,920
63	550	710	475	612	20·2	75	11,760	7·75	156·9	318	...	Tank Locom.	2,000	...		...	...
35	550	710	...	...	24·5	77	14,350	6·90	193·0	254	97 Rs.	3	3,500	13,440	...	40,880	89,600
95	573	705	...	...	27·8	65	8,600	7·10	186·5	261	98	3	1,800	6,720	...	33,472	58,520
95	573	705	479	590	35·5	89	9,600	4·68	158·5	265	99	3	2,290	11,200	...	35,448	68,684
..	492	...	...	...	24·5	51	11,650	8·00	190·0	291	100 Rs.	3 4	3,500 4,500	8,960 11,220	... ...	52,192 67,536	96,152 117,827
..	529	...	...	...	26·7	58	10,800	7·40	194·0	292	... Rs.	3 4	3,570 4,500	8,960 11,220	... ...	49,336 67,536	93,296 117,827
08	435	526	...	...	30·0	74	10,250	6·72	193·0	282	101	3	3,375	11,200	...	27,004	84,896
03	498	562	...	...	32·3	78	11,020	7·75	204·0	306	102	3	3,450	8,960	...	44,800	87,584

2° Two-cylinder compounds and three-cylinder compounds $= \frac{p \cdot d^2 \cdot l}{2\,D}$

Ra. (col. 54) = Ramsbottom scoop.

Group			RAILWAY.	Locomotives.		Longest run without		Average annual mileage, in miles.	*Remarks.*
Number.	Letter.	Index number.		Type.	Number of illustration.	Stop, in miles.	Change of locomotives, in miles.		
1	2	3	4	5	6	7	8	9	10
3	α	...	Belgian State Railway	2 B1	29	75·9 (1)	182·1 (2)	37,300 (3)	(1) Brussels-Ostend. — (2) Ostend-Herbesthal. — (3) Including the locomotives under repair.
3	β	...	Baden State Railway	2 B1	37-39	84·6 (4)	160·2 (5)	70,800 (6)	(4) Karlsruhe-Freiburg. — (5) Mannheim-Bale. — (6) Including the locomotives kept ready and those under repair. Maximum yearly mileage of an individual locomotive, 174,022 kilometres (108,100 miles).
3	γ	1	Paris-Lyons-Mediterranean Railway.	?	?	99·2 (7)	161·1 (8)	58,200 (9) 69,900 (10)	(7) Laroche-Dijon. — (8) Marseilles-Ventimiglia. — (9) Including the locomotives kept ready. — (10) Including the locomotives under repair.
3	γ	2	French State Railway.	2 B1	67	148	147·9	37,500	...
3	γ	3	Midi Railway	?	?	91·7	146·1	54,650 (11) 49,670 (12)	(11) Including the locomotives kept ready. — (12) Including the locomotives under repair.
3	δ	...	Great Central Railway	?	?	164	206	...	
4	α	1	French Eastern Railway.	2 C	72-73	112·4 (13)	162·6 (14)	49,050 (15)	(13) Chaumont-Belfort. — (14) Paris-Chaumont. — (15) Including the locomotives under repair.
4	α	2	French Northern Railway	2 B1	81	119 (16)	184 (17) (230) (18)	52,000 (19)	(16) Arras-Paris. — (17) Paris-Calais. — (18) Formerly : Paris-Liége Nord-express. — (19) Average, 1905/1907; maximum yearly mileage of an individual locomotive, 112,500 kilometres (70·000 miles).
4	α	3	Orleans Railway	?	?	82·6 (20)	215 (21)	79,500 (22) 62,800 (23)	(20) Angoulême-Bordeaux. — (21) Saint-Pierre de Corps (Tours)-Bordeaux. — (22) Including the locomotives kept ready. — (23) Including the locomotives under repair.
4	β	1	Caledonian Railway	?	?	151·25	151·25	78,627	...
4	β	2	Great Eastern Railway	2B	95	130	138	...	...
4	β	3	Great Western Railway.	?	?	226·5 (24)	309	...	(24) Paddington-Plymouth.
4	β	4	Lancashire & Yorkshire Railway.	?	?	47,8	99·1	31,919	...
4	β	5	Midland Railway	2 B, twin expansion.	...	207	207	41,758 (25) 29,682 (26)	(25) Referred to all locomotives of this class. — (26) Excluding the locomotives of this class under shop repair.
			—	2 B compound.	100			36,532 (25) 29,827 (26)	
4	β	6	North Eastern Railway	2 B	101	44·1 (27)	80·6 (28)	41,500	(27) Darlington-York. — (28) Darlington-Newcastle.
4	β	7	South Eastern & Chatham Railway	2 B	102	68·8	68·8	45,000	(29) Including the locomotives under repair.

Composition of the trains.

Group			RAILWAY.	Carriages forming train.			Weight of each carriage			
Number.	Letter.	Index Number.		Number of axles.	Weight, in tons.	Composition according to number of axles of individual carriages.	with *two* axles, in tons.	with *three* axles, in tons.	with *four* axles, in tons.	with *six* axles, in tons.
1	2	3	4	5	6	7	8	9	10	11
3	α	...	Belgian State Railway.	?	246 ÷ 344 (1) 226 (2)	*a*) International express trains : bogie carriages, with concertina connexions. *b*) Equally-fast inland trains : three-axled carriages, between them a saloon carriage on bogies.	... ...	18·7 ÷ 21·6	23·2 ÷ 35·4	...
3	β	...	Baden State Railway	24 ÷ 42	218(3) ÷ 385(4)	Bogie carriages chiefly with four and in some cases also with six axles, with concertina connexions.	...	...	30·5 ÷ 41·3	43·3 ÷ 51·2
3	γ	1	Paris-Lyons-Mediterranean Railway .	30	256	Two luggage vans, each with three axles, six four-axled bogie carriages with concertina connexions.	...	16·3 ; 21·3	32·4 ÷ 39·4	...
3	γ	2	French State Railway	22	197	Two-axled carriages and one four-axled driving car, with concertina connexions.	18·7 ÷ 22·6	...	...	...
3	γ	3	Midi Railway.	20	177	Four-axled bogie carriages with concertina connexions.	...	....	34·4	..
3	δ	...	Great Central Railway.	40 ÷ 60	120 ÷ 230	Bogie carriages, generally with four axles, with concertina connexions.	..	...	28	...
4	α	1	French Eastern Railway	?	148 ÷ 374	Four-axled bogie carriages with concertina connexions.	...	...	31·5 ÷ 36·4,5 26·6 (6)	...
4	α	2	French Northern Railway	...	275 ÷ 335	As a rule four-axled, sometimes also six-axled bogie carriages with concertina connexions; two-axled carriages are also used to a limited extent.	27·5 to 39.3 tons, without particulars of the individual types of carriages			
4	α	3	Orleans Railway.	...	187 ÷ 394	Some trains four-axled, others six axled. Bogie carriages with concertina connexions; some trains with two-axled carriages.	19·4 ÷ 21·2	...	38.2	45·2 ÷ 47·2
4	β	1	Caledonian Railway.	52	330	Ten four-axled and two six-axled bogie carriages with concertina connexions.	...	...	25	40
4	β	2	Great Eastern Railway.	40 ÷ 60	300 ÷ 400	As a rule four-axled, sometimes also six-axled bogie carriages with concertina connexions; also three-axled carriages.	20 to 30 tons, without particulars of the individual types of carriages.			
4	β	3	Great Western Railway	50	400	As a rule four-axled, sometimes also six-axled bogie carriages with concertina connexions.	...	...	33	39
4	β	4	Lancashire & Yorkshire Railway . .	24	151.5	Four-axled bogie carriages without concertina connexions.	...	...	24·9 ÷ 26	...
4	β	5	Midland Railway	26	142	One two-axled, two three-axled, three four-axled and one six-axled corridor carriages (7).	9	13	24 ÷ 27	29
4	β	6	North Eastern Railway	24-30	135 ÷ 215	Four-axled bogie carriages and one six-axled dining car; mostly with concertina connexions.	...	...	21 ÷ 31·75	41·25
4	β	7	South Eastern & Chatham Railway. .		No information.					

Remarks : (1) Section : Ostend-Herbesthal. — (2) Section : Brussels-Antwerp. — (3) Section : Bale-Karlsruhe. — (4) Section : Bale-Heidelberg. — (5) Passenger carriage. — (6) Luggage van. — (7) Order of the carriages according to number of axles, in the train : 3-2-4-3-4-6-4 axles.

SECTIONAL DISCUSSION

Meeting held on 13 July 1910 (morning).

MR. GERSTNER, IN THE CHAIR.

The President. (In French.) — We are now going to consider question VII. I call upon Mr Courtin, reporter for all countries, except America.

Mr. Courtin, *reporter.* (In German.) — The question dealt with in my report has already been considered several times by the International Railway Congress. If you refer back, you will find that at the London session, in 1895, question VI had as title: "Express locomotives". At the Paris session, in 1900, it appeared slightly amplified, as "Locomotives for trains run at very high speeds". Finally, in 1905, at Washington, the question of locomotives for fast trains was considered, if not directly, at least by implication, under the title "Locomotives of great power", which also included goods locomotives. This list shows you the great interest with which the Congress has followed the question. If in spite of the excellent and complete reports brought before preceding sessions, the subject has once more been subjected to investigation, the reason is that ten to fifteen years form a comparatively long period in railway matters, and that it is advisable that this question, which was on the agenda last in 1900, should again be considered today. The impulse was given by the celebrated high-speed trials of electric locomotives on the Marienfelde-Zossen line. It seemed advisable and important to see what results have been obtained with steam locomotives hauling fast trains, as compared with those obtained by the younger electric locomotive.

It was recognized *a priori* that comparatively few administrations would have trains running at speeds exceeding 100 kilometres (62 miles) per hour in the regular service. That was the limit fixed for the inquiry. It was thought advisable to limit the inquiry to speeds exceeding 100 kilometres per hour, because slower speeds are in no way exceptional in the countries considered, but are matters of every-day occurrence. In order, on the other hand, to investigate the question as completely as possible, it was not limited to the locomotives, but also extended to trains and train services.

The answers received confirmed the expectation that trains running at speeds

exceeding 100 kilometres (62 miles) per hour exist in comparatively few countries, Many railway administrations replied that they never use such speeds; many of these informed us that they had no locomotives for such speeds. A second group of railways mentioned that they have, on their system, locomotives capable of running at speeds exceeding 100 kilometres per hour, but added that such speeds were never used, neither when trains where rnnning regularly and to schedule time, nor even when it was a question of making up for lost time. The administrations which have answered in this way include the Danish, Bavarian, Italian, Swedish, and Hungarian State railways. It is hardly necessary to remark, that a considerable number of other railways are in a similar position to those just mentioned, but have not sent any answers; probably, I think, because they have stuck to the strict wording of the question. It was explicitly asked whether there were any locomotives for obtaining regulation speeds exceeding 100 kilometres per hour. As regards railways in Europe, and in particular those I know, the Prussian, Austrian and Wurtemberg State railways, for instance, and sundry other railways, they all possess a large number of locomotives perfectly able to attain speeds exceeding 100 kilometres per hour.

A third group of railways only uses speeds exceeding 100 kilometres (62 miles) per hour exceptionally in the ordinary service, namely when trains are late. This group includes the Baden State Railway, the Belgian State Railway, the French State Railway, the English Great Central Railway, the Paris-Lyons-Mediterranean Railway.

Finally, there is a fourth group of railways consisting of those railways on which trains every day attain regulation speeds exceeding 100 kilometres (62 miles) per hour on suitable sections of the line. These railways are all in France and in Great Britain.

If now before considering the locomotives, I may be allowed to say a few words about speeds and the nature of the lines, we find that in Belgium the speed may attain 110 kilometres (68·4 miles) per hour in cases of delay, on the flat and on down gradients of 5 to 6 per mil, and on curves having a diameter of at least 900 metres (45 chains). The Baden State Railway uses speeds attaining 110 kilometres ·(68·4 miles) per hour on down gradients not steeper than 4·5 per mil and on curves having a radius of not less than 1,100 metres (55 chains); in Germany, this radius is legally prescribed in the *Bau- und Betriebsordnung* as the minimum for a speed of 110 kilometres (68·4 miles) per hour. On several French railways, speeds of 110 to 115 kilometres (68·4 to 71·5 miles) per hour are attained in cases of delay, on down gradients of not more than 5 per mil and on curves having a radius of at least 700 metres (35 chains); the railways in question are the Midi, the Paris-Lyons-Mediterranean and the French State. In the fourth group, using regulation speeds exceeding 100 kilometres (62 miles) per hour in the regular service, France is represented by speeds which may attain 120 kilometres (74·5 miles) per hour. This is the maximum speed fixed by the supreme authorities. It is attained on up gradients of not more than 3·3 per mil, on down gradients of not more than 5 per mil, and on curves

having a radius of at least 500 metres (25 chains). The English railways mentioned use speeds of nearly 129 kilometres (80 English miles) per hour on down gradients of up to 6·25 per mil.

As regards the design of the locomotives, I must, owing to the limited time I have available, refer you to my report, where you will find the chief particulars of the locomotives, given in appendices 2, 3 and 4. I nevertheless think I may briefly refer to several points; I will begin with the number of the axles. With these locomotives, a leading bogie is preferred. As an exception, we find a few locomotives with a leading carrying axle. The number of driving axles varies from one to three. The Great Western Railway has a large number of locomotives with a leading carrying axle. Bavaria is exceptional; it has locomotives with a leading bogie and a trailing bogie. I have recently been informed that this type will be also adopted by the French Northern Railway. With the Bavarian locomotive, speeds of up to 150 kilometres (93 miles) per hour have to my knowledge been attained.

As regards the number of cylinders, two-cylinder locomotives and four-cylinder locomotives exist in about equal numbers. The three-cylinder type is very rare; it only exists on two English railways (Midland and Great Central); the other English locomotives have two cylinders, generally inside. The four-cylinder locomotives are found in other countries. Usually there are two inside cylinders and two outside; the low-pressure cylinders are generally outside and the high-pressure cylinders inside. The Italian State Railway is an exception: the two high-pressure cylinders are both on the left side and the two low-pressure cylinders both on the right.

As regards valve gear, besides the well-known flat slide valve, piston valves of various types are also used, and spring rings are used in all of them. Figures 127 to 129, in my report, show special types of such valves: firstly, the piston valve of a Swedish locomotive, which is designed with internal admission (fig. 127); secondly, the piston valve of the Baden *Pacific* locomotive, with double admission and exhaust, and finally the piston valve of the Danish *Atlantic* locomotive, which has the high-pressure valve and low-pressure valve on one and the same rod.

The question of balancing the masses, which is of importance at such high speeds, is generally solved by completely balancing the eccentrically-placed rotary masses by balance weights, which are either cast in one piece with the wheels or are bolted on to them. On the other hand, the solution of the problem of balancing the reciprocating masses varies a good deal; when there is any balancing, the proportion balanced varies between 5·6 and 29 per cent. In the case of four-cylinder locomotives, it is, as a rule, not applied; one is satisfied with the balancing which results from the opposite directions in which the pistons in the cylinders move, and there is no balancing of any importance, the object being to avoid any centrifugal forces the counterweights would produce. No designs have been mentioned in which, similar to those shown for instance at the 1900 Paris exhibition, the reciprocating masses are balanced by reciprocating counterweights.

The two-cylinder locomotives generally

use single expansion. The Belgian State Railway and the English Great Western have four-cylinder single-expansion locomotives; as might be expected, they use superheated steam.

As regards the working pressure of the boilers, comparatively low pressures, such as 10 to 12 atmospheres, are very rare. One finds much more frequently 13 to 14 atmospheres, particularly in England where the pressure of 12·7 atmospheres or 180 pounds per square inch is usual. The German, Belgian, Danish, French, Hungarian and Italian railways mention pressures of 15 and 16 atmospheres. The older locomotives of course use saturated steam. There are comparatively few locomotives with superheaters among those mentioned in the answers; the German superheated-steam locomotives are as a rule compounds; and the Belgian, Swedish and English are single-expansion locomotives.

The dimensions of the boilers vary within exceptionally wide limits; this could not well be otherwise, seeing the very varying work the locomotives have to do. The heating surface varies between 150 and 250 square metres (between 1,615 and 2,690 square feet); the grate area and the ratio of heating surface to grate area also vary widely. This is due to the quality of the fuel used. When one is in the happy position, as in England, of having fuel of excellent quality, a small grate area suffices. An interesting fact to be noted is that the length of the grate hardly ever exceeds 2·5 metres (8 ft. $2\frac{3}{8}$ in.). It seems that this has been recognized as the limit, beyond which the work of firing becomes too arduous.

As in the case of heating surfaces, the weight of the locomotives and the wheel-loads vary widely. The weights of the locomotives vary from 43 to 90 tons, that is to say by about 100 per cent. There is less difference in the adhesive weights. They vary from 29 to 40 tons in the case of locomotives with two driving axles, and from 42 to 45 tons in that of locomotives with three driving axles. Exceptionally adhesive weights of less than 15 tons and of more than 18 tons per axle are used. On the English locomotives adhesive weights of more than 18 tons per axle are also found.

Devices for reducing air resistance are to be found on a certain number of locomotives, especially on those of certain Danish, French, Italian, Swedish and Hungarian railways. In those cases, the front of the smoke-box and the cab front are made wedge-shaped.

Nearly all the tenders have three axles. The four-axled type is used on some Danish and German locomotives. With the single exception of the Danish tender, which has rigid axles and axles with play, the four-axled tenders are on bogies. The water capacity of the tenders varies between 15 and 20 cubic metres (between 3,300 and 4,400 English gallons); the latter figure is the more usual, no doubt because such modern locomotives are intended to make but few and short stops. The coal capacity varies between 5 and 6 tons and the weight in working order between 35 and 40 tons; exceptionally it attains 58 tons.

An interesting question is that of the braking coefficient of the locomotive and tenders. On many modern locomotives, the brake acts not only on the driving wheels, but also on the bogie wheels and

on the wheels of any carrying axle. The braking coefficient varies from 47 to 82 per cent. The Bavarian 2 B 2 (4-4-4) locomotive, which is equipped with the Westinghouse quick-acting brake, is an exception. With this brake, the initial pressure exceeds the wheel-load, but drops below 100 per cent during the slowing, so that the locking of wheels is avoided. On many railways, the rule adopted in the case of tenders is to brake 100 per cent of their weight, empty.

As regards the runs made by these locomotives, I have more particularly considered the length of non-stop runs, the length of runs without change of locomotive and, finally, the annual mileage of these locomotives. About half the railways have non-stop runs of 100 to 200 kilometres (62 to 124 miles), and on about one fourth there are such runs of 200 and 300 kilometres (124 and 186 miles). Finally, there are two railways, one with a longest non-stop runs of less than 100 kilometres (62 miles), and the other with one of over 300 kilometres (186 miles). The first place is occupied by the English Great Western, which has a non-stop run of 365 kilometres (227 miles). The runs without change of locomotive are in many cases on the same lines as the non-stop runs; here again the English Great Western comes first with a run of 497 kilometres (309 miles). As regards the mean annual mileage of locomotives, I am unfortunately unable to give any comparable figures, as the answers received were based on very different assumptions. The mean annual mileage of a locomotive of a given class varies, if one considers only the locomotives which have actually been used for the service, or if one considers the reserves and the locomotives under repair. I have had to be satisfied with compiling some statistics.

Annual averages of 100,000 kilometres (62,100 miles), including the locomotives under repair but not including reserves, are found on the Baden State Railway (114,000 kilometres [70,800 miles)], the Orleans Railway (101,000 kilometres [62,800 miles]) and the Caledonian Railway (126,000 kilometres [78,300 miles]). It will perhaps be interesting to give the maximum mileage of certain locomotives: a 2 B 1 locomotive of the French Northern Railway has made an annual mileage of 112,000 kilometres (69,600 miles), and an *Atlantic* of the Baden State Railway has run 174,000 kilometres (108,100 miles) in one year.

The composition of the trains varies widely as regards number of axles and weight of vehicles. The weight varies between 122 and 407 tons, corresponding to a number of twenty to sixty axles. Figures exceeding 200 tons are very frequent. Nearly all the carriages have bogies with four or six wheels; carriages with two or three axles are the exception. The trains, moreover, do not always consist only of bogie carriages, or of carriages with two or three axles, but there are trains with carriages having two, three, four or six axles intermingled, and no trouble of any kind seems to result. This may be due to the fact that these carriages with two or three axles have a very long wheelbase and are very heavy, so that any great differences between the weights of the carriages forming one and the same train are avoided.

In conclusion I think I may state that the short investigation, the main results

of which I have just had the honour to bring before you, has led to the satisfactory conclusion that our steam locomotives, which have given good results for a long period of time, still have within them considerable latent resources which may be utilized whenever the profile and the working conditions make this possible, without having to equip our present express locomotives, as now designed and used, with any special devices. I therefore venture to submit to you the following conclusions:

Special locomotives are used in great number in the countries dealt with in the report, for speeds of over 100 kilometres (62 miles) per hour.

Only a limited use of these speeds is however made in the regular train service, either as booked speeds, or for making up lost time.

Nearly all locomotives of this kind have bogies, sometimes also carrying axles; apart from a few rare exceptions, they nearly all have separate tenders.

The number of driving axles generally varies between two and three; however locomotives with only one driving axle are still used, but quite exceptionally.

Locomotives of recent construction frequently have a trailing carrying axle, on account of their large and heavy boilers.

The types of locomotives used are 2 B 1 or 4-4-2, *Atlantic*; 2 C 1 or 4-6-2, *Pacific*; and sometimes 1 C 1 or 2-6-2, *Prairie*.

The bogies and the trailing carrying axles, and sometimes also the driving axles, have a small amount of lateral play, to facilitate running round curves. Most of the locomotives have two or four cylinders; more rarely three cylinders.

The valve gear includes flat slidevalves, either balanced or not, and, especially in the case of locomotives of recent construction, piston valves.

In both classes of valves, devices are occasionally found for increasing the inlet and the outlet ports for the steam.

The rotating masses of the engine are always completely balanced by means of balance weights. The reciprocating masses, on the other hand, are not, or very little, balanced in the case of four-cylinder locomotives with engines set opposite.

Central automatic apparatus for lubricating the cylinders and valves are in use, particularly on the locomotives of recent construction. Devices for reducing air resistance are seen occasionally.

In the case of locomotives of recent construction, there is a tendency to adopt high coefficients of braking, by fitting the brakes not only to the driving axles but also to some or all the carrying axles. Some of the tenders have three and some four axles.

In the latter case bogies are used, exceptionally also carrying axles with lateral play.

Trains running at speeds of over 100 kilometres (62 miles) per hour consist nearly exclusively of stock on bogies with two or three axles. One however also sees trains consisting of bogie carriages, and of carriages with two or three axles having a long wheelbase and a great weight.

The President. (In German.) — As Mr. Garstang, reporter for America, is absent, I request Dr. Dudley kindly to give us a summary of his report.

Dr. P. H. Dudley, New York Central & Hudson River Railroad. — In the introduction of this paper, it is presumed that all members have read the report and definitely understand that the questions covered by the tabulated portion, were framed upon lines suggested by my colleague, Mr. Alex. Courtin, on request, in order that replies for America would be comparable with those concerning Euro-

pean administrations contained in the paper presented by Mr. Courtin.

It is further presumed that all members appreciate the difficulty and liability to error that would have confronted the author if he had attempted to reduce the English system of measurements, which is standard in America, to the metric system current in European continental practice and will therefore, kindly frame all questions they may care to propound in discussing the paper so far as dimensions are concerned to the English standard.

This paper, throughout the text and illustrations, is drawn distinctly on American lines and as such may vary greatly from the European report of my colleague, but from the standpoint of the author, we feel that all statements have been made distinct and clear and are therefore freely comprehensible.

As stated in the first paragraph of the report, the replies for America would have been so extremely limited as to make a paper of this character of no value if the question in its original form had been insisted upon, and we feel that all American railway administrations who are honoured by membership in this Association have been greatly favoured by the courtesy of Mr. Weissenbruch, who personally obliged the author by reducing the original speed of sixty miles per hour to fifty miles in order that America might be represented in a befitting manner.

We hope the Congress will appreciate our reasons for a reduction in the speed limit and will endorse the secretary's action in the revision, which action would be more than appreciated by the author.

Further, Mr. Garstang calls attention to the abbreviated form of his paper and the reasons; therefore, the absence of purely technical information in the form in which it would appeal to continental engineers is accounted for, but he would further say that the rapid increase in speed of trains in America, will warrant a continuation of this subject, and if such is done ample time should be given to the fortunate reporter and he will have our assistance in working up any technical information from this paper that he may desire to use.

I should like to add to the general statements of Mr. Garstang the reporter that for the long distance trains which run 960 to 1,158 miles to complete their time schedules, the actual speeds on portions of the lines are daily from 70 to 75 miles per hour and 80 is often exceeded with trains of 500 to 700 tons.

The class K 2 E, or 4-6-2, locomotives compared with the class I, 4-4-2 locomotives, though heavier, loads the track more favorably and is easier on the permanent way from its longer driving wheel base and expending its 1,200 to 1,500 horse-power through six drivers instead of four.

The locomotive rides steadier in service as would be expected from experimental tests of its strains in the rails.

The President. (In French.) — Gentlemen, as the discussion of question VII may take some time, I propose to adjourn it to this afternoon.

Meeting held on 13 July, 1910 (afternoon).

Mr. Zehnder, Bavarian State Railway. (In German.) — Among the most powerful locomotives mentioned in Mr. Courtin's report, there are those of the Bavarian State Railway. Allow me to give you particulars of the work they do.

The maximum speed of the Bavarian 2 B 2 locomotives is fixed at 150 kilometres (93 miles) per hour, and that of the 2 C 1 locomotives at 120 kilometres (74·5 miles) per hour. The 2 C 1 locomotive can haul a train weighing 400 tons on the flat at a speed of 110 to 120 kilometres (68·4 to 74·5 miles) per hour, on an up gradient of 5 per mil at one of 90 kilometres (56 miles), and on an up gradient of 10 per mil at one of 60 to 65 kilometres (37·3 to 40·4 miles) per hour. If the weight hauled amounts to 500 tons a speed of 90 kilometres (56 miles) per hour is still attained on the flat. As a general rule, the speed of the trains is only 80 to 90 kilometres (50 to 56 miles) per hour. The fuel consumption then amounts to 12 kilograms (42·58 lb. per mile) and the water consumption to 80 kilograms per kilometre (283·84 lb. per mile). The working monthly mileage of these locomotives is 11,000 to 12,000 kilometres (68,350 to 74,560 miles). As their tenders take 26 cubic metres (5,720 English gallons) of water, runs varying from 250 to 300 kilometres (155 to 186 miles), according to the profile of the line, can be made before taking in water.

Mr. Noltein, Moscow-Kazan Railway. (In German.) — I should like to say a few words with the object of inserting in the conclusions, as far as possible, something with a view to the classification of locomotives intended for very high speeds, from the point of view of their action on the track. Above all, I think it should be emphasized that a modern locomotive for fast trains should have a leading bogie, and I will ask you to mention this point in our resolutions.

I am one of the few members of this section who have also attended meetings of the first section, and I must state that our track colleagues think that we are far from paying sufficient attention to their wishes regarding the treatment of the track. I will therefore begin by speaking of some essential differences. In the first place there will be that which exists between locomotives with a leading carrying axle and locomotives with a leading guiding bogie.

Here are two drawings; the upper one represents a locomotive with a leading carrying axle and the lower one a locomotive with a leading bogie. These drawings are intended to show the action of the locomotive on the track, both on straights and on curves. You see, in the upper drawing, that there is a certain depression under each axle, so that a locomotive with several axles produces the deformation of the track shown in the drawing. I particularly wish to remark that it is above all thanks to the researches of Mr. Dudley, which were described at the Washington session, that we know how to regard the theory that locomotives

with axles near together are worse for the track than locomotives with axles further apart; the arguments brought forward by Mr. Dudley have absolutely refuted this theory and today all engineers agree that it is on the contrary advantageous to have the axles as near together as possible. Between two successive axles a sort of wave is formed, and the greater the distance between the axles, the greater the sagitta of that wave, and with it the fatigue of the sleeper. It is impossible to think that a locomotive with a single leading carrying axle is as good as one with a bogie, for the distance between the carrying axle and the leading driving axle (if the latter is properly loaded and if the carrying axle is to guide the locomotive properly on curves) is necessarily greater than the distance between the second axle of the bogie and the leading coupled axle. It follows that a longer wave is formed between the leading carrying axle and the first coupled axle than between the second bogie axle and the same coupled axle.

On the other hand, it is advantageous to have the axles loaded unequally, and to have the leading axle less loaded. Then the tangents to the curved rail form a smaller angle with the horizontal and the fatigue of the metal is less. It is much better to use one bogie with two axles, each with a load of 11 tons, than a single axle with a load of 13 tons, acting on the track direct. The action of these two types on the track may be described as follows : if the horizontal line *ed* is the position of the unloaded rail, and if F, with the suffixes 1 and 2, is the height of the wave between the leading coupled axle and the axle in front of it (figs. 1 and 2), then if H, the depression of the coupled axle, is constant, F_2 will generally be much greater than F_1.

That is of advantage to the track; for the smaller the height of the waves the better. If F_2 attained the value H, this would prove that the following axle acted directly on the track, similar to the preceding axle. The smaller the height of the wave, the weaker the action on the track, for the angles of inclination of the tangents to the elastic curve of the rail are then also smaller. Thus we see that it is always possible to design a bogie locomotive so as to fatigue the track less than a more or less similar locomotive with carrying axle. And as each of the axles of the bogie has a smaller load than the single carrying axle, the curvature of the rail in front of the leading axle and under the bogie is more gradual than with the single carrying axle, as shown in figures 1 and 2.

But the whole difference is not limited to this; it becomes much more marked if we compare the whole of the forces, vertical and horizontal, which the carrying axles exercise upon the track.

The two kinds of forces depend on two kinds of causes; partly they are due to properties generally inherent in the ordinary types of tracks and to the normal reciprocal action between the vehicle and the track; partly they are due to irregularities and defective adjustment of the track.

As regards all the forces due to the causes of the second kind, the bogie acts as a large equalizer for the two axles, so that the deviations of the pivot referred to its normal path are produced with velocities and accelerations half as large as the deviations of a single carrying axle. Consequently, in the case of the bogie all

forces of the second kind, exercising a destructive action on the track and on the vehicle, are half as large as they are in the case of a single carrying axle.

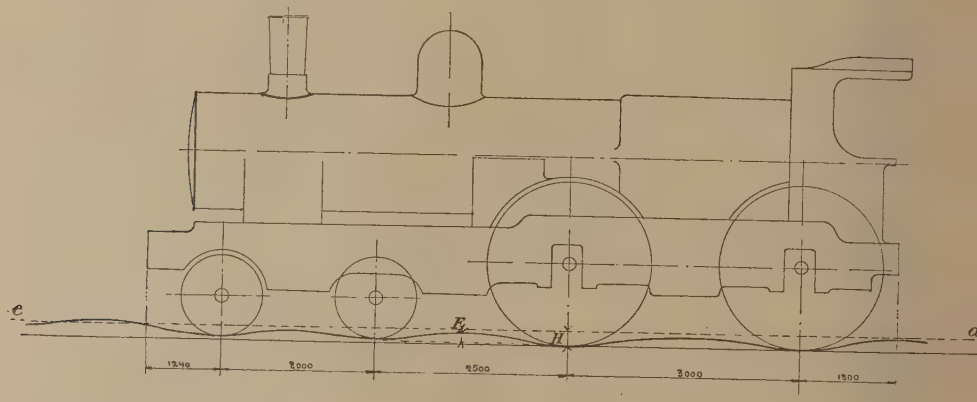


Fig. 1.

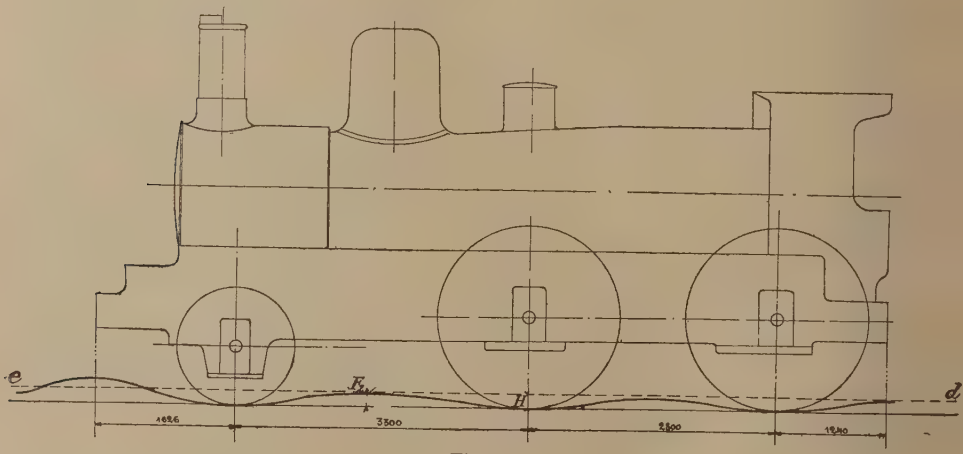


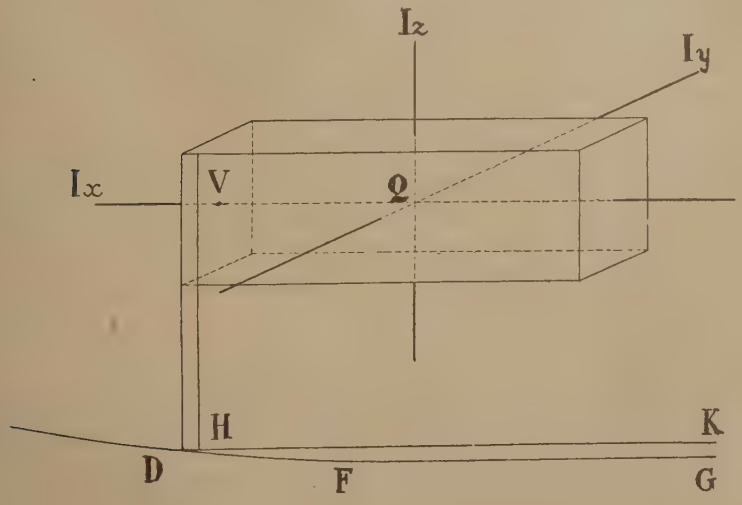
Fig. 2.

These remarks only apply to carrying axles and to bogie axles; but it must not be forgotten that here it is a question above all of these axles, for the coupled axles only act on the rails when these are already depressed and acted on by the carrying axles, their stability being consequently materially increased.

Our tracks are designed primarily with a view to vertical forces and have much less resistance in the horizontal direction. I will explain the results which can be

obtained from this point of view by the rational design of the locomotive, with the help of figures 3 to 6, which represent a parallelipipedon. I would remind you that when it is a question of a rigid structure, of a solid body, the way in which this body behaves depends on its mechanical properties. The mechanical character of a rigid body depends on its mass and on the three moments of inertia which are the moments of inertia referred to the three principal axles. We can accordingly imagine any body whatever replaced by a simple body of this kind, provided it has the same moments of inertia. Thus we have represented the body of a locomotive by such an elongated cube. On this figure you see a branching line, the lower part of which is a curve. This line is intended to represent the track at a curve. Now when a locomotive runs round a curve, we must distinguish between the regular movement, that is the movement when the whole of the locomotive is on the curve, and the movement when it enters the curve.

Fig. 3.



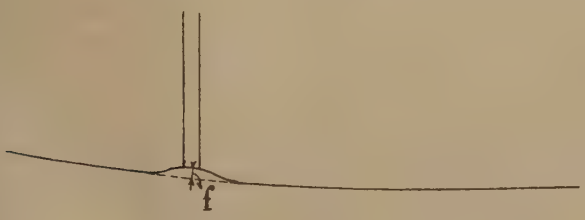


Fig. 4.

Fig. 5.

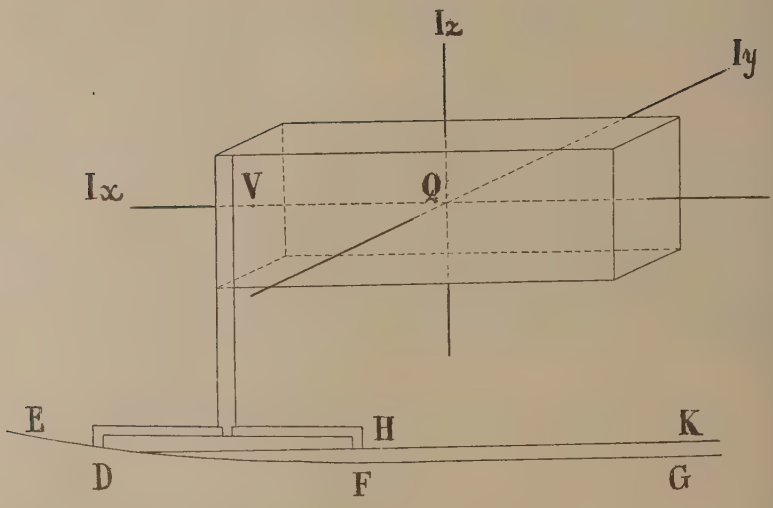


Fig. 6.

We shall see that the latter is by far the more important, as the track is then more fatigued by the locomotive. I will begin with the regular movement. When the whole of the locomotive is on the curve, special forces come into play between the tires of the locomotive and the rail (figs. 4 and 6), and that for two reasons. The first is, that on a curve the friction between the tires and the rails has to be overcome, for the locomotive, which has a tendency to continue to move in a straight line, is continually deviated laterally. The forces resulting thereupon can be determined very accurately; they are not very large and attain, in the most unfavourable case, 3,000 to 5,000 kilograms (6,600 to 11,000 lb.) as regards the guiding flange of the leading carrying axle of a locomotive running light, and about half that amount in the case of a bogie axle. In addition to these forces, there are those due to want of truth of the track. Here I have drawn a curve, with a projecting part, which represents, on an enlarged scale, such an irregularity. Now assume

that a locomotive with a single carrying axle reaches this point; the carrying axle will be suddenly deviated and the locomotive will receive a shock laterally. In consequence of this sudden movement, the different parts of the locomotive and of the track are subjected to very definite stresses. If the locomotive has a leading bogie, the same shock is always transmitted through the bogie centre. If we put f for the sagitta of the untrue track, the maximum lateral deviation is only $f/_2$, and consequently the forces acting between the flange and the rail are one fourth as large as in the first case, for the force, only one half as great, is divided between two axles. You see that in this case again the forces produced are much smaller in the case of a bogie than in that of a single carrying axle. No doubt when a bogie is running over such an irregularity, two small deviations are produced instead of a single larger one. Now as we know, two small forces are always of much less importance than a single large one, so that in this case again the bogie is incontestably superior.

We may also note that the special forces produced by the irregularities in the adjustment of the track can be materially reduced by giving the leading axle or bogie a certain amount of lateral play. But all such arrangements can be combined more rationally with a bogie than with a single carrying axle.

Finally, we have to examine the case of entering the curve. Figure 3 corresponds to a locomotive with a carrying axle; the lower part of the branch is supposed to be in the same plane as the outer edge of the guiding flange of the carrying axle. FG is the inner edge of the rail, on the straight; HK corresponds to the outer side of the flange. The locomotive is running on the straight until it reaches point D; there the flange comes in contact with the rail. A deviation is there produced, consequently the whole parallelipipedon moves, and the velocity of that deviation is greater, the greater the speed of the locomotive and the greater the angle FHK; accordingly, if there is much play between the flanges of the wheels and the rails the velocity of the deviation becomes greater. As we can only fix this play within limits (for instance assuming the flanges are not too much worn), we only have certain values of this velocity to consider. In the case of a bogie locomotive (fig. 5), approximately the same is the case, with this difference that the deviation of the centre of the bogie does not begin at the moment the flange touches the rail, but only after the second axle of the bogie has become sufficiently inclined relatively to the rail to make the flange of the second axle come in contact with the rail. Then approximately equal forces become developed at the flanges of the two axles, with the result of deviating the pivot forming the centre of the bogie. You see, gentlemen, that in this case, two forces act and produce the deviation, while in the other case, that of the single carrying axle, there is only one force. The action on the track is hence much more violent in the case of the single carrying axle. It is true that when there is a single axle it is generally placed rather further forward than the bogie centre; consequently the length of the arm of the lever of deviation VQ becomes a little greater and this is a great advantage, particularly if one remembers that the action of the length of this lever

varies not proportionately to its first power, but varies proportionately to the square of that length. Calculation nevertheless shows that with a bogie the track is much less fatigued than with a carrying axle.

Besides the ordinary bogie, we have also to consider another system, the Krauss-Helmholtz truck, in which the carrying axle is connected with the first coupled axle by means of a lever the pivot of which is generally fitted with a check spring acting laterally. This arrangement acts in a way like a bogie, but it must be recognized that the bogie has advantages, for the leading coupled axle is acted on by other forces besides those necessary for guiding the locomotive. Moreover, the mass of a coupled axle is always much greater than the mass of a carrying axle, the axle-boxes in one piece form another weight which is not hung, etc., so that the Krauss truck can in a way be described as a bogie of the second class.

The third class will include the Bissel truck, which has the advantage that the deviation takes place progressively, by the intermediacy of a spring; another advantage is reduced friction, due to the flexible truck. Finally, after the Bissel truck there would come the rigid carrying axle, which is the most imperfect device. When one has studied the action of the locomotive on the track both theoretically and practically, one arrives necessarily at the conclusion that the different types can be arranged in order of merit in these four principal classes. In other words, the two-axled bogie is the best, then comes the Helmholtz-Krauss truck, then the Bissel truck and finally the rigid carrying axle.

It would be very advisable, without entering into details, at least to mention the principal classes in our resolutions. In spite of the great importance of some of these details, it is above all a question of the fundamental properties of the four classes in question. That is all that I have to say concerning the conclusions.

I will now allow myself to add sundry remarks concerning the effect of the recent strengthening of the tracks. Up till now we have had to do with rather light rails which acted, within the existing load limits, as a kind of spring, much reducing the forces acting on the locomotives. In cases of contact of the levers of deviation H and EH (figs. 3 and 5) with the rail, there was deviation of the latter, and this deviation appreciably reduced the forces acting, while increasing the times during which they acted. With stiff rails, they still become bent, but much less. Consequently, it is also necessary to strengthen our locomotives a little as regards those parts affected by running on a stiffer track or provide for efficient elastic suspension within the frame of the locomotive. You see, moreover, how important it is to raise the centre of gravity of the locomotive, for the higher that centre above rail-level, the longer the arm of the lever determining the deviation as compared with the longitudinal horizontal axis, so that the guiding is effected not only by rotation about the vertical axis, but also by rotation about the horizontal axis through the centre of gravity. Consequently, the deviation at H (fig. 3) or at EH (fig. 5) takes place much more easily at the moment of entering the curve.

It must not however be thought that there is no longer any limit to the raising

of the centre line of the boiler of the locomotive and that there is an advantage in every case. The reasoning would be true if the raising of the boiler did not affect the moment of inertia of the whole. The arm of the lever of deviation would then increase, without increasing the moment of inertia. Now the rigid system of the locomotive consists of two parts, the frame and the boiler, and if we take those two parts separately, the arm of the lever of deviation is not alone in growing; the moment of inertia also increases very appreciably. It is for this reason that the centre of gravity of the locomotive should not be raised without restriction and as much as possible. I may tell you that I have worked out this calculation for the express locomotives used on the Moscow-Kazan line. I have calculated the action of the elongation of the arms of the lever of deviation and of the increase of the moments of inertia on the fatigue of the rails, for boilers 2·5 and 3 metres (8 ft. 2 3/8 in. and 9 ft. 10 in.) above rail-level, and I found a difference of 8 per cent in favour of the higher boiler. In other words, raising the boiler from 2·5 to 3 metres reduces the action on the track by 8 per cent.

Finally, I would add a word of the great importance, as regards the investigation of express locomotives, of a complete knowledge of the lateral displacements of the bogie, when it has a swing bolster.

Figures 3 and 5 represent the deviation when there is no such device. The lateral deviation of the single carrying axle commences at the point D, where the straight line KH meets the curve FD, and that of the bogie at the moment when the second axle bears against the outer line of rail. If a bolster or a spring is used, the deviation does not begin at once, but a certain movement is produced inside the bogie. If this movement is produced too easily at the start, it may happen that the deviation is slight up to the moment when the bearing of the pivot comes into non-elastic contact with the frame of the bogie. In that case, the deviation will accordingly begin much later. Now the later the deviation, the greater will be the angle of deviation, suddenly produced; consequently, in this case, the forces acting on the rail increase materially, so that it is essential for the spring to be strong enough to prevent this second shock. If this result is attained, one can say that the lateral deviation of the bogie is exactly as desired.

Those are the remarks which I wished to be allowed to submit to you.

Mr. Greppi, Italian State Railway. (In French.) — I have listened to Mr. Noltein's very interesting statement. I do not know whether I have quite understood what he said. I think however that the question, interesting though it may be, is above all a theoretical question which it is not possible to discuss without careful preliminary examination. On the Italian railways, we have a considerable number of locomotives in use with the leading carrying axle interlinked with the first coupled axle; the whole forms a bogie the pivot of which supports the weight of the front part of the locomotive. The pivot has lateral play, with readjustment by means of check springs. Locomotives of this type run very well at speeds of 100 kilometres (62 miles) per hour and have even made up to 120 kilometres (74·5 miles) per hour.

Before therefore giving any opinion on such a theoretical and specialized question, it should be examined more fully. Moreover, I do not think that it is a subject the details of which should be discussed by an association like ours.

Mr. Courtin, *reporter*. (In German.) — I wish to express my particular gratitude to Mr. Noltein for the extremely-interesting communication he has made, and which one can certainly accept from the purely theoretical point of view. But in many cases theory and practice are two different things. Theory can after all not include and foresee all that may turn up in practice. Mr. Noltein tells us that he considers the forces acting in a horizontal plane and in a vertical plane, as far as that is possible. I think I may summarize his explanations by saying that bogies are to be preferred for high speeds. It may however be questioned whether it is justifiable to describe, as being less safe, the leading carrying axle, in a formal resolution of the International Railway Congress, with all the authority inherent in such a resolution. That seems to me a delicate matter, for as far as I know the theory of the subject is not yet sufficiently advanced to include and express correctly all the interactions of the wheel and the rail. One should therefore, as regards this point also, take practical experience as basis.

Now leaving theory and passing to practice, I can state that answers have been received from two well-known and important administrations who have 81 locomotives of the 1 C 1 (2-6-2) type, with a leading carrying axle, three coupled axles and a trailing carrying axle. These locomotives run at speeds of up to 80 miles, say 130 kilometres per hour. One French railway, the Paris-Lyons-Mediterranean Railway, has informed us that it has 53 locomotives with a leading carrying axle and four cylinders, running at up to 115 kilometres (71·5 miles) per hour. Such is practice, and evidently no trouble has resulted.

Mr. Salomon, French Eastern Railway. (In French.) — In support of Mr. Courtin's remarks, I will remind you that before using bogie locomotives, the French Eastern Railway, just like the French Northern and the Paris-Lyons-Mediterranean, used Crampton locomotives for high speeds, that is locomotives having only a single leading carrying axle.

Subsequently the French Eastern Railway, like the Midi Railway, used locomotives with two coupled axles and a leading carrying axle; these could attain a maximum speed of 120 kilometres (74·5 miles) per hour. In about eleven years, a series of sixty two of these locomotives gave a total mileage of 35 million kilometres (21,748,000 miles). It is true that these locomotives only ran on our trunk lines, Paris-Belfort and Paris-Avricourt. The load on the leading carrying axle was 14 tons. The permanent-way department, during this long period, did not find any deformation, any damage which could be attributed to these locomotives. This result is no doubt due to the fact that the weight of these locomotives was properly distributed and that the lines in question have curves with a very large radius only.

Mr. Chabal, Paris-Lyons-Mediterranean Railway. (In French.) — I think there is a mistake as to the number of locomotives

of this kind. We have only had one locomotive of this kind with which we allowed the driver to do 115 kilometres (71·5 miles) per hour.

Mr. Courtin. (In German.) — The number is given as two in one case and as forty in the other.

Mr. Chabal. (In French.) — No; the latter are bogie locomotives.

Mr. Courtin. (In French.) — That is not stated in the answers to the list of questions.

Mr. Chabal. (In French.) — That is possible, but in any case it is a mistake and I wished to draw attention to it. Actually there has been only one such locomotive used for high-speed work.

Mr. Courtin. (In German.) — Then it is a mistake made in the answer sent by the Paris-Lyons-Mediterranean Railway; the wording of the answer is shown to support this statement.

The President. (In German.) — I should like the discussion to be shortened. It is half past three and we must finish today. To morrow afternoon there is already a general meeting. I think that our honourable colleague, Mr. Noltein, should not urge that his remarks, which have much interested us, should appear in the conclusions; it would be better if he drew up a paper on the subject for the *Bulletin*.

Mr. Herdner, Midi Railway. (In French.) — We have not drafted any conclusions.

The President. (In French.) — We are going to submit draft conclusions to you.

Mr. Noltein. (In German.) — I wish to clear up a misunderstanding. I am far from saying that an express train cannot be hauled by a locomotive having a leading carrying axle. There are locomotives which, as the honourable reporter has mentioned, have done very good work; that fact has been known for a long time. As for me, it was a question of examining what was the influence of these locomotives on the track, and of investigating what types of locomotives, in the present state of the art of locomotive building, are most to be recommended. That, after all, is all that is asked of us.

The President. (In German.) — You have heard what Mr. Salomon said?

Mr. Noltein. (In German.) — I have heard something very different at the 1st section. There people were always saying : we must strengthen the rails, we every day receive new locomotives which fatigue the track more and more.

I will allow myself to ask the President kindly to ask the Permanent Commission, instead of investigating, as formerly, on the one hand, the strengthening of the track, on the other, locomotives for high speeds, that it should investigate the question including both points, that is to say, the reciprocal action of track and locomotive. In this way we shall arrive at conclusions really important to railways. Thus we were informed in the 1st section that rails weighing 52 kilograms per metre (104·83 lb. per yard) no longer satisfied the requirements of certain lines. I think that this involves a serious misunderstanding. I think that the progress we have made in the design of locomotives is not sufficiently appreciated by railway administrations. If certain lines require much maintenance, the fault is

not the great weight of heavy modern locomotives, but perhaps not enough investigation or the deficiencies of older but lighter locomotives.

The President. (In German.) — What is a summary of your suggestions?

Mr. Noltein. (In German.) — I ask that the question I have just enunciated should be placed on the agenda for the next session of the Congress.

The President. (In German.) — We agree with Mr. Noltein that it should be recorded in the minutes that the section has listened to Mr. Noltein's very interesting statement and that the speaker in conclusion asked that the Permanent Commission should include, among the agenda for the next session of the Congress, the question of the mutual relations between the track and heavy locomotives from the point of view of wear. The section will no doubt agree that this can be done. (*Approval.*)

Mr. Noltein. (In German.) — That is my proposal exactly. I should next like to ask another question. Is open link motion or motion with crossed rods used?

Mr. Courtin. (In German.) — I did not expect this question. In Germany, we generally have link motion with crossed rods, and everybody is satisfied with this. According to my own experience and according to what I have seen in works dealing with this subject, this mechanism gives rise to no difficulty, whatever the speed.

Mr. Noltein. (In German.) — It follows from Mr. Garstang's report that our American colleagues find that the Stephenson link motion, which is used generally, is superior to the Heusinger link motion.

It would be very interesting to know whether the Americans prefer, in the case of high-speed locomotives, open rods or crossed rods (1).

The President. — I request Mr. Dudley kindly to answer, if possible, the question asked by Mr. Noltein.

Dr. P. H. Dudley. — The New York Central Lines use the open excentric rods in their Stephenson's valve gears and most of the other railway systems in the United States observe the same construction.

Mr. Noltein. (In German.) — Can Mr. Dudley tell us the reasons why Mr. Garstang did not consider the Walschaerts motion superior to the Stephenson?

Dr P. H. Dudley. — I could not, for the reason that Mr. Garstang had only expressed his opinion in reference to them on page 29 of his report (2) without full explanation as to all details, and I do not wish to interpret or convey a wrong impression of his experience.

The President. (In French.) — I invite Mr. Noltein to place himself, personally and by letter, in communication with the author of the report.

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(1) Vide Mr. Garstang's report, p. 29, and also *Bulletin of the Railway Congress*, number of February, 1910, p. 721.

(2) *Note.* — It would seem proper to refer those interested to Mr. Garstang's statements on page 29 (p. 721 of the number of February, 1910, of the *Bulletin of the Railway Congress*); since the report was written, subsequent service on the New York Central Lines indicates that his opinions were clearly expressed and well taken.

I have already stated what the matter is. Mr. Noltein simply asks that the Permanent Commission should place on the agenda for the next session of the Congress the question of the mutual relations between the track and heavy locomotives.

I think that we can close the general discussion and pass to the examination of the conclusions to be adopted by the section.

Mr. Courtin and Mr. Garstang's representative, Dr. Dudley, have been kind enough to draft a set of conclusions which I now have the honour to read out to you :

" 1° Special locomotives are used in great number in Europe and in America for speeds of over 100 kilometres (62 miles) per hour. Only a limited use of these speeds is however made in the ordinary service, because it is preferred to choose speeds below this limit on lines with much traffic in order to make it possible to haul heavier trains."

— Adopted.

" 2° The locomotives of this kind are in most cases equipped with leading bogies, sometimes also with leading carrying axles; apart from a few rare exceptions, they nearly all have separate tenders."

— Adopted.

" 3° The number of driving axles is in most cases two or three. The recent locomotives often have a trailing carrying axle, on account of the large dimensions of the boilers.

" Designs : 2 B 1 or 4-4-2, *Atlantic* type; 2 C 1 or 4-6-2, *Pacific* type; sometimes also 1 C 1 or 2-6-2, *Prairie* type."

— Adopted.

" 4° The bogies and carrying axles, and sometimes also the driving axles, have a small amount of lateral play, to facilitate running round curves."

— Adopted.

" 5° Most of the locomotives have two or four cylinders; more rarely three cylinders."

— Adopted.

" 6° The valve gear includes flat slide-valves, either balanced or not, or, especially in the case of newer locomotives, piston valves."

Mr. Noltein. (In German.) — It would seem that flat slide-valves are used in the great majority of cases.

The President. (In German.) — Quite so. It is only in the case of high pressures and in that of compound locomotives using superheated steam that it is usual to have piston valves for the high pressure and flat slide-valves for the low pressure, with superheated steam.

" 7° Continuous-action lubricators are used for the cylinders and the valves."

There are also steam lubricators, the Nathan lubricator, and sight-feed lubricators. They are continuous, but not mechanically-operated. Do you wish that we should say automatic lubricators or continuous-action lubricators? Strictly speaking these are not continuous-action lubricators, for when the locomotive is

not running the lubricator also does not work.

Mr. Herdner. (In French.) — The expression " *graisseurs automatiques* " is not used in France. The usual term is " *graisseurs continus* ".

The President. (In French.) — We will accordingly say : " Continuous-action lubricators for the cylinders and the valves." It is enough if the French delegates understand what we mean.

" 8° Devices for reducing air resistance are occasionally seen."

— Adopted.

" 9° There is a tendency to adopt high coefficients of braking by fitting brakes to the carrying axles."

We might perhaps say : " To the bogie axles and the carrying axles." The former are also carrying axles but as a rule we do not include them under that designation.

Mr. Herdner (In French.) — The bogie axles are considered as carrying axles. Does the French text agree well with the German?

The President. (In French) — Perfectly.

" 10° Some of the tenders hauled have three and some four axles. In the latter case bogies are used, exceptionally also rigid axles with centralizing mechanism."

That is the device of the Danes.

Mr. Herdner. (In French.) — It is a question of free flexible axles

Mr. Courtin. (In French.) — No, these axles are not flexible. They only have lateral play.

The President. (In French.) — Then let us say " with lateral play ".

" 10° Some of the tenders hauled have three and some four axles. In the latter case bogies are used, exceptionally also rigid axles with lateral play."

— If no objections are raised, I declare these conclusions adopted.

DISCUSSION AT THE GENERAL MEETING

Meeting held on 16 July, 1910 (morning).

Mr. P. WEISSENBACH, president, in the chair.

General secretary : Mr. L. WEISSENBRUCH.

First assistant general secretary : Mr. MÜRSET.

Second assistant general secretary : Dr. A. BONZON.

The president read the

Report of the 2nd section.

(See *Journal de la huitième session*, No. 11, p. 5)

" Mr. Courtin gave a summary of his report and read out the following conclusions :

" Special locomotives are used in great number in *Europe* and in *America* for speeds of over 100 kilometres (62 miles) per hour.

" Only a limited use of these speeds is however made in the regular train service, either as booked speeds, or for making up lost time.

" Nearly all locomotives of this kind have bogies, sometimes also carrying axles; apart from a few rare exceptions, they nearly all have separate tenders.

" The number of driving axles generally varies between two and three, but locomotives having only one driving axle are also used, but quite exceptionally.

" Locomotives of recent construction frequently have a trailing carrying axle, on account of their large boilers.

" The types of locomotives used are : 2B1 or 4-4-2, *Atlantic;* 2C1 or 4-6-2, *Pacific;* and sometimes 1C1 or 2-6-2, *Prairie.*

" The bogies and the trailing carrying axles, and sometimes also the driving axles, have a small amount of lateral play, to facilitate running round curves. Most of the locomotives have two or four cylinders; more rarely three cylinders.

" The valve gear includes flat slide-valves, either balanced or not, and, especially in the case of locomotives of recent construction, piston valves.

" In both classes of valves devices are occasionally found for increasing the inlet and the outlet ports for the steam.

" The rotating masses of the engine are always completely balanced by means of

balance weights. The reciprocating masses, on the other hand, are not, or very little, balanced in the case of four-cylinder locomotives with engines set opposite.

" Central automatic apparatus for lubricating the cylinders and valves are in use, particularly on the locomotives of recent construction. Devices for reducing air resistance are seen occasionally.

" In the case of locomotives of recent construction there is a tendency to adopt high coefficients of braking, by fitting the brakes not only to the driving axles but also to some or all the carrying axles. Some of the tenders have three and some four axles.

" In the latter case bogies are used, exceptionally also carrying axles with lateral play.

" Trains running at speeds of over 100 kilometres (62 miles) per hour consist nearly exclusively of stock on bogies with two or three axles. One however also sees trains consisting of bogie carriages, and of carriages with two or three axles having a long wheelbase and a great weight."

" Mr. P. H. Dudley (*New York Central & Hudson River Railroad*) read a summary of the report of Mr. Garstang, who was absent; and speaking for himself, he added that in the case of trains running a distance of from 1,545 to 1,864 kilometres (960 to 1,158 miles), the booked speeds varied from 112 to 120 kilometres (70 to 75 miles) per hour, with loads of 450 to 625 tons; speeds of 129 kilometres (80 miles) per hour were often exceeded. In spite of the weight of locomotives of the *Pacific* (4-6-2) type, which was greater than that of the *Atlantic* (4-4-2) type, the load was better distributed over the track, which became less worn because the wheelbase was longer and because the 1,200 to 1,500 horse-power were distributed over six driving wheels instead of only four.

" Locomotives of the *Pacific* type ran more smoothly than had been expected from the trials made for determining the wear of rails.

" Mr. Zehnder (*Bavarian State Railway*) mentioned that the speed of the 2 B 2 locomotives had been fixed at 150 kilometres (93 miles) per hour, and that of the 2 C 1 locomotives at 120 kilometres (75 miles) per hour. The latter could haul 400 tons (393 English tons) at speeds of 110 to 120 kilometres (68 to 75 miles) per hour on the flat, of 90 kilometres (56 miles) per hour on up-gradients of 5 per mil and of 60 to 65 kilometres (37 to 40 miles) per hour on up-gradients of 10 per mil.

" Generally the speed attained by the trains was 80 to 90 kilometres (50 to 56 miles) per hour; under these conditions the locomotives consumed 12 kilograms of coal and 80 kilograms of water per kilometre (42·5 lb. and 238·8 lb. respectively per mile). The mileage of these locomotives was about 12,000 kilometres (7,456 miles) per month.

" As the tenders could hold 26 cubic metres (5,720 gallons) of water, distances of 250 to 300 kilometres (155 to 186 miles) could be covered without taking in water.

" Mr. Noltein (*Moscow-Kazan Railway*) gave an interesting explanation of the influence of the bogies and leading carrying axles both as regarded the stability of the locomotive and the preservation of the track.

" He referred to the investigations made

by Mr. P. H. Dudley (Washington, 1905), according to which it was advisable to reduce the distance between the axles, as it was in the case of locomotives with bogies, so as to reduce the bending of the rail.

" The horizontal reactions were also smaller with the bogies because the lateral reactions were distributed over two axles, and this facilitated the entry on curves.

" The *Krauss-Helmholtz* truck did not act so well as the bogie, as in the former case the coupled axle was more heavily loaded than the carrying axle.

" The different devices could be placed in the following order of relative value : 1° bogie; 2° *Krauss-Helmholtz* truck; 3° Bissel truck (with controlling gear); 4° fixed carrying axle.

" The strengthening of the track also involved a strengthening of the locomotives. The high position of the boiler also had a favourable influence on the smoothness of running of the locomotives. Finally, the speaker expressed the wish that the use of bogies for high-speed locomotives should be recommended.

" Mr. Greppi (*Italian State Railway*) said that in Italy they had a large number of locomotives with a leading carrying axle and running at a speed of 100 kilometres (62 miles) per hour; they gave every satisfaction. It would be very advisable and desirable that the theoretical points raised in Mr. Noltein's report should be investigated more closely.

" Mr. Courtin (*reporter*) thought that everybody agreed that bogies were to be preferred in the case of high-speed locomotives. He however mentioned two railways, the *Great Western* and the *Paris-Lyons-Mediterranean*, which had locomotives with a single leading carrying axle, and ran at high speeds in the regular service; this showed that the use of such carrying axles was not excluded in practice.

" Mr. Salomon (*French Eastern Railway*) called to mind that the *French Eastern Railway*, the *French Northern Railway* and the *Paris-Lyons-Mediterranean Railway* had had in use locomotives with a single leading carrying axle; these locomotives were of the *Crampton* type and ran at very high speeds without any bad influence on the track.

" Later on the *French Eastern Railway*, the *Midi Railway*, and other railways built locomotives with two coupled axles and a leading carrying axle; these ran at 110 kilometres (68·4 miles) per hour without any bad effect on the track.

" The load on the carrying axle was 14 tons (13·77 English tons) It was right to mention that the distribution of the weight on the axles was very good, and that the *Paris-Belfort* and *Paris-Avricourt* lines, on which these locomotives ran, had curves of large radius only.

" Mr. Noltein remarked that as the 1st section was considering the subject of the strengthening of the track, he proposed that the Permanent Commission should be requested to submit to next Congress the question of the action of heavy locomotives on the track and *vice versa*.

" Mr. Noltein referred to Mr. Garstang's report, according to which Stephenson valve gear was preferable to that of Walschaerts, because the former was a variable lead gear. The speaker on the

contrary found that the constant lead was an advantage of the Walschaerts gear.

" Mr. COURTIN was of the same opinion; he stated that the Heusinger-Walschaerts gear fitted both to express locomotives and to goods locomotives gave every satisfaction.

" The section then adopted the following proposed conclusions. "

The President. (In French.) — The following are the

CONCLUSIONS.

" 1° Special locomotives are used in " great number in Europe and in America for speeds of over 100 kilometres " (62 miles) per hour. Only a limited " use of these speeds is however made " in the ordinary service, because it is " preferred to choose speeds below this " limit on lines with much traffic in " order to make it possible to haul heavier " trains.

" 2° The locomotives of this kind are " in most cases equipped with leading " bogies, sometimes also with leading " carrying axles; apart from a few rare " exceptions, they nearly all have separate " tenders.

" 3° The number of driving axles is in " most cases two or three. The recent " locomotives often have a trailing carrying axle, on account of the large dimensions of the boilers.

" Designs : 2 B 1 or 4-4-2, *Atlantic* type; " 2 C 1 or 4-6-2, *Pacific* type; sometimes " also 1 C 1 or 2-6-2, *Prairie* type.

" 4° The bogies and carrying axles, and " sometimes also the driving axles, have " a small amount of lateral play, to facilitate running round curves.

" 5° Most of the locomotives have two " or four cylinders; more rarely three " cylinders.

" 6° The valve gear includes flat slide-" valves, either balanced or not, or, especially in the case of newer locomotives, " piston valves.

" 7° Continuous-action lubricators are " used for the cylinders and the valves;

" 8° Devices for reducing air resistance " are occasionally seen.

" 9° There is a tendency to adopt high " coefficients of braking by fitting brakes " to the carrying axles.

" 10° Some of the tenders hauled have " three and some four axles. In the latter " case bogies are used, exceptionally also " rigid axles with lateral play."

— These conclusions were confirmed by the general meeting.

[621 .135.2]

APPENDIX

Note on steel tires for high speed locomotives,

By Dr P. H. DUDLEY,
CONSULTING ENGINEER NEW YORK CENTRAL LINES.

The development and running of the heavy loads of five (5) to ten (10) tons per wheel for high speed trains have indicated the fact that it is difficult for the manufacturer to produce sufficient mechanical work upon the metal of a thirty-three (33) or thirty-six (36) inch tender, coach or truck tire to give the steel of every tire of the ingot uniform physical properties for the entire circumference of the treads. This was possible for the lesser strains of the lighter wheel loads and slower trains of a decade ago. Higher and more uniform physical properties per ingot are required for the entire metal of the circumference of each tire per melt for heavy wheel loads and high speeds.

Figure 1 represents an eccentric steel tire which developed on a tender wheel originally of thirty-six (36) inches in diameter but by being turned one or more times had reduced to thirty-two and one-half (32 1/2) inches. Two-thirds of the circumference of the tire withstood the results of service, only those portions of the metal of lower physical properties being deformed, but this was sufficient to make an eccentric tire which not only shelled but caused severe impacts upon the rails under the rapidly moving trains. This is nearly typical of the eccentric tires which develop in the central thickness of the original metal after they have been turned one or more times. The texture of the steel is usually coarse and fragile, incident to the soaking in the furnaces at high temperatures to which it was subjected in fabrication.

Eccentric and shelled tires develop with greater rapidity in the winter than summer due in part to two distinct effects of the falling temperatures upon the metal of the tire.

The first effect is due to the contraction of the metal of the tire augmenting the shrinkage strains upon its wheel centre ;

The second effect is due to the unequal contraction between the components of the mineral aggregates of the metal increasing its fragility in service as the temperature falls.

The metal in some tires has entrained im-

purities which become the starting point of the failure in the different portions of the tread. In other types of eccentric tires the deformation is local and confined to a few inches of the tread. These are known to have developed in some cases in one or two trips.

Figure 2 represents a tire from the mate wheel on the axle which has performed the same service and the metal in the entire circumference proved of adequate physical properties to sustain the wheel loads without irregular deformation.

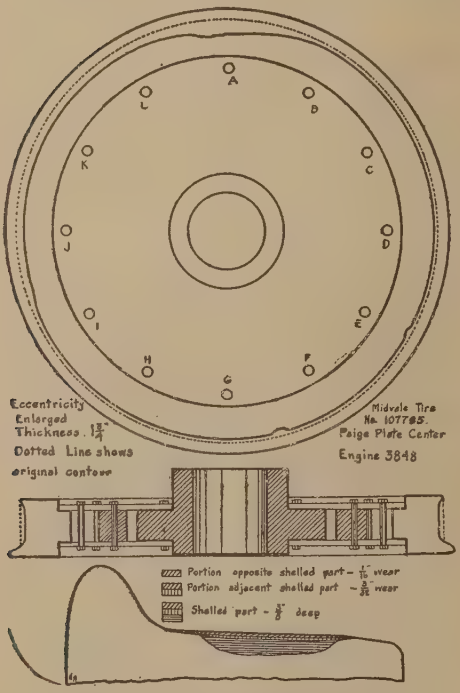

Fig. 1. — Eccentric and shelled tender tire.

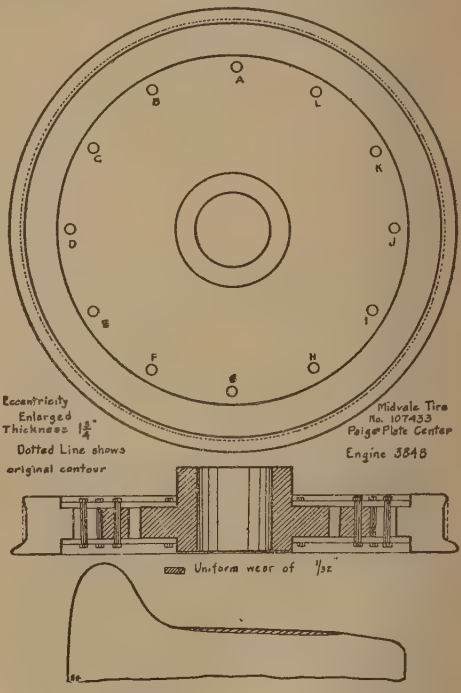

Fig. 2. — Unshelled mate from same axle as fig. 1.

Figs. 1 and 2. — New York Central lines. — Department of tests and inspection.

Tonnage upon rails and wheels.

Rails. — The tonnage supported by a given portion of the bearing surface of a rail due to a passing wheel contact is the static load of construction plus its generated wheel effects; therefore, the total tonnage is the product of only the number of passing static loads of construction and their generated wheel effects.

Wheels. — The tonnage sustained by the metal of the treads of the wheels is the static load of construction plus the generated wheel effects multiplied by the number of revolutions; therefore, the tonnage accumulates more rapidly than upon rails.

The total tonnage of the equipment is divided between two rails; therefore, the amount they will sustain before renewal accumulates many times slower than on wheels.

The tire receives and sustains its load each revolution upon every portion of its circumference. The thirty-six (36) inch tender, coach and Pullman car wheels make five hundred and sixty and two-tenths (560·2) revolutions per mile. The maximum load upon the tender wheels by construction is ten and two-tenth (10·2) tons but the average load is about nine (9) tons, or five thousand, forty-one and eight-tenths (5,041·8) tons per mile, and for a run of one hundred and fifty (150) miles in three hours and fifteen minutes would be a static load for each tender wheel of seven-hundred and fifty-six thousand, two-hundred and seventy (756,270) tons. The generated wheel effects would add from twenty to fifty per cent additional at high speeds, depending upon how smooth or even the treads maintained their circumference. A tender tire which became eccentric ran twenty-nine thousand (29,000) miles before it was removed and its total tonnage approximated one-hundred and forty-six million (146,000,000) tons for about six months service.

The tonnage on Pullman car wheels of five tons per wheel is equivalent to a static load of two thousand, eight hundred and one (2,801) tons per mile, and the tonnage per trips would be as follows:

Boston to Chicago.	1,023 miles	×	2,801 tons	= 2,865,423 tons.
New York to Chicago.	964 —	×	2,801 —	= 2,700,164 —
New York to St. Louis	1,158 —	×	2,801 —	= 3,243,558 —
New York to Cincinnati	885 —	×	2,801 —	= 2,478,885 —

The generated wheel effects will add from twenty to forty per cent additional tonnage according to the smoothness of the tread and track.

While the total tonnage on the Pullman car wheels for a trip is much greater than that experienced upon the tender wheels of the locomotives, yet the intensity of the unit stresses upon the tender wheels is from two to three times as great for each individual repetition as occurs upon the Pullman car wheels. It is for this reason that they are able to withstand so many more repetitions of these lighter loads before the treads shell or become visibly affected. The unit intensity of the stresses not being as much as on the tender wheels the wear and deformation of the tire is not as rapid, though some shelled and broke the past winter in America.

The locomotive drivers of large diameter though carrying a heavier wheel load do not accumulate tonnage upon the tread of the tires as rapidly as the tender wheels. The seventy-nine inch drivers make two-hundred and fifty-five and three-tenths (255·3) revolutions per mile, and with a static load of fourteen and thirty-four hundredths (14·34) tons, or three thousand, six-hundred and sixty-one (3,661) tons per mile for a trip of one-hundred and fifty (150) miles the total tonnage would be five-hundred and forty-nine thousand, one-hundred and fifty (549,150) tons. The same drivers for one-hundred thousand miles before shopping the total tonnage would be three-hundred and sixty-six million, one-hun-

dred thousand (366,100,000) tons, while the generated wheel effects would add from thirty to sixty per cent.

Generated wheel effects.

The opinion of previous reporters, and some of those present, is that the generated wheel effects might increase the total load upon the wheels fifty (50) per cent. This would depend to some extent on the condition of the wheel tread. It is a well-known fact that the generated wheel effects upon the stiffer rails in present use are much less than those upon the former lighter sections. The experience of running engines at sixty (60) and seventy (70) miles per hour shows that with the wheel treads in good condition the wheel effects do not rise to fifty (50) per cent of the total load after acceleration and the uniform motion of the train has been attained. The application of the brakes for deceleration also increases the percentage of wheel effects. When the tread of the wheel becomes eccentric then the wheel effects may exceed fifty (50) per cent of the load and in many cases more than double the total loads upon the wheel in its impact upon the rails.

The reporters upon special steels and tires state that in every country difficulties are experienced in securing metal which renders satisfactory service in tires. The ordinary carbon steels must be well deoxidized and purified for the metal to be of sufficient physical properties to carry the heavy wheel loads of eight (8) and ten (10) tons per wheel for tires of thirty-three (33) and thirty-six (36) inches in diameter. The work upon the metal in fabrication is much less for the smaller diameter than occurs for the tires for the driving wheels. The service rendered by driving wheel tires on the *Pacific* type of locomotives, class K-2E, New York Central & Hudson River Railroad, of which the average static wheel load is twenty-eight thousand six hundred (28,600) pounds, is from one-hundred thousand to one-hundred and twenty-five thousand (100,000 to 125,000) miles before they require shopping for re-turning. The thirty-six (36) inch tire under the tender has a maximum static load of twenty-thousand three-hundred and seventy-five (20,375) pounds when loaded and few of these tires run more than thirty thousand (30,000) miles before they require shopping for re-turning. The wheel effects under the tender tires are greater in proportion to their load and speed owing to the greater intensity of the wheel pressures and more rapid increase of the irregularity of the tread than under the locomotive drivers. More attention will be paid in the future to these differences of service and metal selected to meet the increased conditions of wear and deformation to make the tender tires do a greater service before they require re-turning. Tests are now being made of oil hardened and annealed tires for this service, also metal of higher grade of purity and more uniform physical properties in the entire circumference of the tread. Problems are now better understood than heretofore and there is but little question but that decided improvements will be made which will conduce to the betterment of the tires for service.

SECTION II : LOCOMOTIVES AND ROLLING STOCK

[621 .33]

QUESTION VIII

ELECTRIC TRACTION

Electric traction on large railroads. Continuous current. Alternating current (monophase or polyphase). Comparative net cost.

Reporters :

Germany. — Dr. Gleichmann, State councillor of the Bavarian Board of works, Munich.

America. — Mr. Geo. Gibbs, chief engineer of electric traction, Long Island Railroad.

Austria and Hungary. — Mr. Arthur Hruschka, Dr. Techn., K. K. Baurat and reporter of the Department commissioned by the Austrian Railway Administration for studying and preparing the introduction of electric traction on the State Railway.

Other Countries. — Dr. W. Wyssling, professor at the Federal polytechnic School, manager of the electricity works of the canton of Zurich, general secretary of the Swiss electric traction investigation commission.

QUESTION VIII

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Report No. 3 (Austria and Hungary), by Mr. A. Hruschka. (See English edition of the *Bulletin* of June, 1910 [2nd part], p. 2711.)	VIII — 111
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N. B. — Vide also the separate issues (in red cover) Nos. 19, 35 and 59.

[621 .33]

REPORT N° 2

(America)

By GEORGE GIBBS,

CHIEF ENGINEER OF ELECTRIC TRACTION, LONG ISLAND RAILROAD,
CHIEF ENGINEER OF ELECTRIC TRACTION, PENNSYLVANIA TUNNEL AND TERMINAL RAILROAD.

INTRODUCTION.

It is understood that the scope of this paper is confined to American practice in electric traction under steam railroad conditions, and especially to the subject of conversion of existing steam railroads to the new traction method; it does not include haulage by single car units in urban service, nor the extension of such method to light interurban or cross-country trolley roads. These latter roads have in some instance developed into quite extensive railway systems, operating over private right of way, and approximating in distances and speeds the conditions of steam railroads, but differing from steam railways in the elaboration of provisions for train handling, in equipment of line with stations, yards, signals, etc., and in organization for conducting a general transportation business, local and foreign, in both passengers and commodities.

The subject of electric traction is of very live interest to railway men, from the standpoint of possible economies in existing operating methods and from that of the retention and development of their business in competition with new railways designed exclusively for the new traction method.

Historical reference.

History in electric traction has been made rapidly. The first commercial application in America of electric motors for traction purposes was for street railways in the year 1888, and so demonstrated its advantages over animal traction as to result in its rapid introduction for such service in the various cities throughout the country. To this kind of road its application was confined until in 1895 when the Baltimore & Ohio Railroad Company undertook the bold experiment of equipping for electric haulage its tunnel line and terminal in the City of Baltimore. This installation anticipated many intermediate steps in the development of the new art, as it was designed to haul electrically the heaviest main line trains, freight and passenger, over a line which, while short, contained a heavy continuous grade. While in many ways an experiment, the installation demonstrated the physical possibility of heavy electric traction and accomplished its purpose of smoke elimination in the tunnel.

The first demonstration of the usefulness of electric traction for suburban passenger traffic, was on a short elevated railway at the Chicago World's Fair in 1893, where light trains were electrically hauled around the Exhibition grounds. This was followed in 1895, by the equipment of a new elevated railway system (the Metropolitan) in the same city, in both of these cases, motor cars at the head of the train hauled trailers. The next installation, in 1898, another elevated railway system in Chicago, displaced steam locomotive haulage, and recorded a further and important stage in the development of the art, namely, the introduction of the " multiple unit " system of train operation. This consisted of the equipment of several cars in a train with motors, and the simultaneous control of same from the head-end car. These installations established standards for the successive conversion of all elevated traction systems in the country, and secured the advantage of steam locomotive elimination in city traction, and a greatly increased capacity of the lines and average speed of service.

After the Baltimore & Ohio installation no further application of electricity, which may be considered within the scope of this report, was made until 1905, when a portion of the suburban lines of the Long Island Railroad, out of New York City, was converted. This installation constitutes the real point of departure in the development under discussion; it was at the time and remains still the most extensive conversion of an existing steam railway for the handling of suburban traffic by multiple unit electric trains. It was followed in 1906 by a similar equipment of the West Jersey & Seashore Railroad (Pennsylvania system) from Camden, near Philadelphia, to Atlantic City, sixty-five miles distant. This may be considered the first example of electric traction for main line express service.

In the same year, another step is recorded by the opening of electrical operation on the New York Central & Hudson River Railway into its New York City terminal.

It may be taken as the first example of very heavy trunk line terminal electric operation for all passenger trains, and will be extended, when the construction of the new terminal is complete, to electric haulage of all trains within a 30 mile zone. This was followed in 1907 by the equipment of the New York, New Haven & Hartford Railroad into New York, dictated primarily by the condition of its entrance over the New York Central, and adapted to conduct electrically a very dense local and through service on a four track railway for thirty-four miles out of the City. Of the above distance, thirteen miles over the New York Central tracks are included.

Electric traction for cross-country freight haulage was inaugurated in 1907 on a new line, the Spokane & Inland Railway, in the State of Washington. While not coming under the head of steam railway conversions, it is an example of electric traction under steam railway conditions. In the same year, electric service was inaugurated on a division of the West Shore Railroad (New York Central system) between Utica and Syracuse, and also on a portion of the Rochester Division of the Erie Railroad. Both of these installations are in the nature of tests of the economic and traffic fostering effects of electric traction applied to local passenger service on steam railways.

In 1908, the Grand Trunk Railway's tunnel line under the Detroit River at Sarnia, Ontario, was converted; it is an example of an intermediate line in a main line using electricity to haul passenger and freight trains under special local conditions.

In 1909, the Great Northern Railway Company's installation through its Cascade tunnel, State of Washington, was completed. It was undertaken, as in the case of the Baltimore and the Sarnia tunnels, primarily to eliminate smoke in a long tunnel, but with the view of later extending the system for haulage over a mountain division of a Western trunk railway line.

It is expected that by the time this report is before the Congress that the important enterprise of the Pennsylvania Railroad in bringing its main line traffic into the City of New York through tunnels under the Hudson and the East Rivers, will be completed and in operation. The undertaking of this great project was predicated upon the use of electricity for haulage.

The above historical reference comprehends the important events in America in developing the new method of traction for the variety of conditions met with on steam railways. In the appendix will be found a brief summary of the characteristics of the various installations.

It will be seen that practically all steam railway conditions have been covered by the installations cited above, many of them of a highly important and extensive character. The next phase of the situation involves observation of operating results, perfection of method, and a determination of the extent to which the supercession of the steam locomotive is warranted by either economic or traffic conditions.

Systems employed.

These will be referred to in very general terms only, as it is unnecessary for the purposes of this report to describe in detail the electrical characteristics of the various traction systems.

First developments were by the " direct current " system, that is, generation of direct current in a power house, its transmission at generated voltage along line conductors, either trolley or third rail, and its utilization in direct current motors.

This system was modified, as the distances and magnitude of power requirements increased, by alternating current generation, its transmission at relatively high voltages, its transformation to lower voltages and conversion into direct current at substations, to be fed into the line conductors and utilized in direct current motors as before. Practically all applications of heavy traction up to 1907 employed this latter system, which for brevity will be referred to as the " A. C.-D. C. " system.

In 1907, the straight A. C. system came into use; it comprehends the generation of alternating current, transmitting it as single phase at relatively high voltage to the line conductors, and transforming in electric locomotives to low voltage and utilization in alternating current motors; the system may be briefly referred to as the " Single-Phase ". Examples of this system are found in the Spokane & Inland, the Grand Trunk, and the New York, New Haven & Hartford installations.

The Great Northern Railway's Cascade tunnel installation inaugurated in America the " Polyphase Alternating Current " system. Three-phase alternating current is generated and fed into line conductors at relatively high voltage and transformed and utilized in three-phase motors on the locomotive. It may be referred to briefly as the " Three-Phase " system.

Elements of all these systems are alike in so far as they employ central station generation of current, its transmission to continuous " working conductors " adjacent to the tracks, from which the current is collected for use in motors on the trains. They differ in detail appliances throughout, and many features of their individual characteristics are matters of high importance and interest to the student of the subject, but cannot be properly discussed in a general paper of this kind. Their differentiation to the steam railway operating official, will most largely lie in the system of " working conductors " and the method of current collection employed, and in the relative simplicity of methods necessary for their operation and maintenance and in their power capabilities, flexibility and economy.

Of the various systems referred to, all except the straight " direct current " are in process of development for application to heavy railway purposes; the " direct current " may be ruled out because of its limited radius of proper application. A system, which has not been referred to, and which, unfortunately, does not appear to be in sight for general railway conditions, is electric traction by self-contained power apparatus on the locomotives or cars, in other words, a system which eliminates the line working conductor, the key-note of present development.

Whatever the state of perfection of this element of an electric traction system, its elimination would not be greatly regretted by the practical railway man. As the A. C.-D. C. system has been longer and in much more extensive use than any other, more facts and figures from operation are obtainable regarding it, and discussion of results must, therefore, largely apply to that system. Doubtless another year will furnish much information as to the behaviour of the interesting " single-phase " and " three-phase " systems, and it is hoped that discussion at the Congress will supplement this report in respect to these systems especially.

Operating methods.

The character of the service determines whether motor cars or locomotives are employed; in this respect, electric traction differs from steam, in which all service is conducted by locomotives. In general, electric traction methods tend in America to the use of multiple-unit trains for all short runs and local services. Electric locomotives are employed only where necessary, that is, for long express runs where the cars must go beyond the electric zone; for special freight service such as heavy grade pusher and tunnel work, and for terminal shunting. Such a division is logical, since it utilizes one peculiar possibility of electric traction, *i. e.*, the possible concentration of great power on the train by equipping any desired number of axles with motors, and thus utilizing any desired portion of its weight for driving adhesion at the rails. The result is rapid acceleration of the train from rest, and a consequent quickening of time where stops and starts are frequent. The importance of this characteristic of multiple-unit trains is illustrated, when it is said that local runs are largely supported by a class of passengers, known as " commuters ", who travel daily to and from business. As a rule, a longer journey than sixty minutes each way daily is inadmissible, or, say, a distance of twenty-four miles by the fastest steam local trains making stops one to two miles apart. A multiple-unit electric train will cover, under these conditions, a 25 per cent greater distance in the same time, or, say, 30 miles; or it will make a 24 mile run in forty-five minutes instead of sixty minutes. In other words, increased electric speed means to an important class of railway patrons, either 25 per cent less time on the road daily, or the ability to live further from the city without increasing the time spent on the journey. This increase of local run radius is obviously a consideration of importance to a railway in holding a large class of traffic and in fostering its growth.

Further and important facts, which are leading to the general adoption of multiple-unit trains, is their characteristic of great flexibility in train make-up without the necessity of complicated and time-consuming switching in terminals, and the ease of turning and dispatching trains at close headway while occupying the minimum of space at expensive terminals. The fullest utilization of these advantages requires that each car in the train shall be a motor car, but where the service is fairly light, it is frequently advantageous to make a certain number of the cars in

a train " trailers " to economize in first cost and weight of train for a given seating capacity.

When electric locomotives are employed the operating methods do not greatly differ from steam locomotive practice, except that electric locomotives permit of more convenient double-heading, as they may be controlled as a single unit.

Character of equipment.

Under this heading will be summarized the general characteristics of the important features of prevailing practice in electric equipment, with a brief reference to their reliability and adequacy for the required service.

Power houses. — Central steam-power plants are in nearly all cases employed, as hydro-electric plants are not generally available in the Eastern portion of the country. Extension in radius of transmission by the use of very high voltages will, doubtless, in the future, enable water power to be used to some extent, although the number of possible sources of such power is limited in the thickly settled portions of the country, and the economy resulting from its development not always as great as supposed; this because of the fluctuating character of a railway load, and from the fact that it is generally not possible to locate a hydro-electric station centrally with reference to the traction loading, or, even, to place it on the line of the railway itself. In such cases, the problem of transmission over foreign or purchased right of way becomes an important one in the electrification plan, and the costs and operating inconveniences of a badly located plant may become an offset to any figured saving. In a number of early installations a duplication of power houses was thought desirable, to provide a safeguard in case of breakdown in one power house, and frequently the low transmission voltage dictated more than one plant for reasons of economy in transmission copper. Of late, however, the tendency is to concentrate power development in a single plant, as it has been found that a total breakdown of a modern power plant is of rare occurence and a temporary shutdown is of such short duration that operation can be resumed in the plant in less time that it would take to conduct the complicated manipulations necessary to obtain sufficient power from the auxiliary plant. Furthermore, the use of two or more plants involves a greater first cost in standby machinery, a lower load factor for each plant and increased operating costs.

Transmission lines. — Except in large cities, overhead transmission lines are generally used. These are set on substantial poles or towers, preferably of steel, and when two or more circuits are employed, it has been found unnecessary to duplicate pole lines, as the total disablement of the main trunk line is of rare occurence. The principal failures in transmission lines have been due to breakages of insulators, generally maliciously, and to lightning disturbances; these failures,

however, generally extend only to the disablement of the one circuit. Trunk lines on steel poles or towers may carry as many as five to eight three-wire circuits of bare hard drawn copper stranded cable, of about 0·2 square inch section. For transmission distances up to twenty miles, 11,000 volts has been the common standard; for longer distances there is a tendency to increase the transmission voltage to 22,000, 33,000, 66,000 and even higher.

In large cities, underground cable transmission becomes necessary; the cables are drawn into conduits of terra-cotta set in concrete and have manholes four hundred feet apart. The cables are quite generally of the three-conductor paper insulated lead covered type. Underground lines are objectionable where they can be avoided because of their very great first cost, and the difficulty of securing a permanent location and proper drainage. They are subject to an indeterminate amount of deterioration by reason of moisture and electrolysis, and in case of a break down of insulation, they cannot be cheaply or promptly repaired. A combination of overhead and underground transmission should be especially avoided, because of danger to the cables from lightning; where the combination line is absolutely necessary, the entrance to and exit from the underground portion must be protected by lightning arrester apparatus.

Substations. — The A. C.-D. C. system requires substations containing transforming and converting machinery, to change the alternating current transmitted from the power station to direct currect of the voltage used at the cars. These stations are set at the maximum permissible distances apart for economy in feeder copper. Generally the distances will not exceed eight miles between stations. In practical operation, these substations have been found to be extremely reliable; the machinery used is simple and capable of standing heavy fluctuations in load without injury, so that it is of rare occurence that any failure of current supply from them is reported.

In the earlier railway installations the rotary converter substations, above described, were often supplemented by storage battery substations, to insure absolute continuity of current to the trains in case of temporary breakdown either in the substation or transmission lines, these battery stations having a sufficient capacity to carry the load for an hour or two. There were, furthermore, intended to act as load equalizers for the power house and rotary substations, and thus conduce to economy of apparatus and operation. Battery stations were justified in these pioneer installations by the great importance of their insurance feature, at a time when experience with rotary converter stations and cross-country transmission lines was limited and their reliability undetermined. At the present time, however, storage battery substations are seldom installed for heavy electric traction, as they have been found unnecessary, either from the standpoint of insurance or economy in operation. In cases where they have been installed, it is now found more economical to consider them purely as insurance features and not as regulators

of load fluctuations; they are therefore generally kept fully charged and are not regularly thrown on the line.

In alternating current systems, both single and polyphase, substations or their equivalent are also used, but they are much simpler and cheaper than in the case of the A. C.-D. C. system. They are at times merely sectionalizing stations to divide the line into feeder sections but they may also be used to transform from a high transmission to a lower line voltage. Because of the high working conductor voltage employed, these substations can be set at less frequent intervals than for the A. C.-D. C. system, the distances apart being dictated largely by sectionalizing and switching conditions. As they contain no moving machinery they, in certain cases, need no regular attendants, thus eliminating a considerable item of operating expense in the A. C.-D. C. system; but for important lines attendants will probably be found necessary for emergency and switching operation, and to insure reliability in operation of the system as a whole and the prompt localization of faults.

Working conductor. — By this term is meant the continuous conductor or conductors over or adjacent to the track, to supply power to the trains by contact of the collectors on the cars. The well known form of overhead trolley wire successfully used for light single car service, is unsuitable for heavy high speed traction, because of the insufficient capacity of the wire to supply the current, the difficulty of maintaining contact at speed and of collecting large currents from a small surface. For the A. C.-D. C. system a " third rail " has been substituted; this is located adjacent to the track served and mounted on insulators set on the ties. Often it takes the form of a standard " T " track rail, but of late a special section and grade of soft steel, to increase its conductivity, is coming into use. In the Pennsylvania Railroad installation, this conductor weighs 150 lb. per yard and is equivalent in conductivity to 1·9 square inch cross section of copper. Quite generally the third rail is protected from accidental contact by a wooden covering, but in cross-country railways having fenced right of way, the covering is often omitted. The American Railway Association has recently established a standard location and clearance for third rail working conductors (see appendix), to facilitate interchange of traffic between different railways and with the view of preventing encroachments by rolling stock and other equipment upon the space necessary for the third rail.

Two types of third rail (see appendix B), have been generally employed, the " top contact " and the " under contact ". In the former type, current is collected by a shoe rubbing on its top; it is the kind first employed and the one still most extensively used. The latter has an underneath rubbing contact surface; it has lately come into use on a number of important installations; its first and up-keep costs are greater than in the case of the top contact rail, but it can be more thoroughly protected from accidental contact by persons and from the clogging effects of snow and sleet.

The voltages used on the third rail vary from 500 to 650 and were originally fixed by the conditions of motor design which limited the practicable pressure to this maximum. Recent improvements in direct current motors, will, however, permit of the use of a higher voltage up to, say, 1,200, and it has been suggested that this higher voltage be used in the working conductors, reducing the current requirements for equal power to one-half of that needed at 600 volts; this economizes in the conductor and feeder system and in the number of substations needed. Experience with this 1,200 volt D. C. system, has not been as yet sufficiently extended to demonstrate that it will practically meet all the conditions on ordinary railroads. It would seem that difficulty will be encountered in using such a high voltage collector rail under average railroad conditions, and that increased danger to employees and others will result. Experience shows that with 600 volts pressure, third rail insulation can be maintained practically even in cases where the insulators are coated with dirt and moisture, but when the potential is raised substantially, maintenance difficulties are increased. It should be remembered that conditions are not ideal near a railway track, and apparatus should therefore be of a character to operate even when somewhat neglected or abused.

Introduction of the straight A. C. systems of traction has caused a reversion to the use of overhead working conductors, instead of a third rail, because of the high voltages employed. A high conductor voltage is the essence of these systems, and constitutes the important point of departure from electrification methods previously described. The working conductor is the part of a traction system which may be considered the most vulnerable — the means for the continuous application of power to the train being through a moving contact. A high tension contact point has made necessary, or allowable, if it is pleased to so consider it, an entire change in the physical character of the working conductor, to the great betterment it is claimed of the main and weak link in the chain of elements of a complete system. Its advocates claim that increased economy in first cost, simplicity of installation and reliability of operation follow the use of an overhead conductor.

For high speed heavy work, the construction of this overhead system is radically different from that of the ordinary light trolley road construction, suitable for low tension direct current work; the so called " catenary " method of suspension is employed to maintain the trolley wire in a true plane parallel with the track, improved insulation methods are necessary, and the collector on the car takes the form of a sliding shoe. The system is still quite new and in process of evolution, and it is yet too early to speak with certainty of its practical results in heavy railway work. Difficulties have been experienced in maintaining the trolley wire in a uniform plane and at the same time in providing sufficient vertical flexibility and compensation for expansion and contraction, due to temperature changes, to secure sparkless collection of current for heavy trains at high speeds. At moderate speeds, say, below forty miles per hour, sparkless collection is not difficult of attainment, but at higher speeds it becomes so and sparking is frequent and troublesome and

results in rapid wear of the collector shoes. It is found also that " hard spots " in the line, such as caused by switches and dips under bridges, etc., are especially objectionable in causing sparking and wear and tear on the overhead construction. Meeting all these conditions becomes more difficult on multiple track lines, but much progress has been made in working out the details of a successful high tension overhead collector system.

As to the third rail ; its characteristics and limitations are fairly well understood from a number of years experience with systems using it. Generally speaking, it has demonstrated its reliability; it has not been found specially dangerous either to employees or others; it has not increased appreciably the cost or difficulty of maintaining the track; and it provides a reliable means for practically sparkless collection of large currents to trains at high speeds. The objectionable features of a third rail may be generally stated as follows : In complicated yards it is, in places, impossible to arrange the rail so as to maintain continuous contact for electric locomotives, and auxiliary overhead contact must be used also; with multiple unit trains exceeding two cars in length, however, continuous contact can in all places be maintained without the use of overhead structures. In winter trouble may occur from snow and ice forming on the rail, causing sparking and loss of contact. Snow is not generally troublesome unless deep, dry and drifting; but in America sudden changes of weather are met with at the beginning and end of winter and occasionally result in a light and cold rain which will form ice on a rail previously chilled below the freezing point. The ice can be removed by special cutters fitted to the trucks of the cars, or by allowing a solution of chloride of calcium to drop on the rail from a slowly moving car, but the suddenness of these storms, makes it at times difficult to apply remedies in time to prevent delays. Overhead high tension line conductors are not wholly free from ice trouble, but delays less frequently result.

Motors. — The direct current 600 volt railway motor has been brought to a high state of mechanical and electrical efficiency. The latest type employs " interpoles ", that is, small compensating poles between the main field poles; they effect a marked increase in the limit of good commutation and practically eliminate " flash-overs ".

The increase in car weights has made it desirable to increase the motor weight and capacity from time to time until the limit appears to have been reached in size of motor which it is advisable to place on a bogie truck. This practical limit is fixed both by the maximum allowable truck dimensions and the maximum gear and pinion pressures practicable for durability. The present maximum motor is that commercially known as of 200 horse-power at the one hour rating. It will, with forced ventilation, carry at 600 volts 200 amperes continuously, giving a continuous capacity of 140 horse-power. Forced ventilation is accomplished by mounting a small motor-driven blower on the truck or car body so as to deliver a large volume of low pressure air into the motor casings. The scheme has been in successful use

on the Long Island Railroad for the past year, and is being adopted for all their new equipments. Tests have shown that with a blower of one horse-power capacity the continuous capacity of the car motors is increased by about 40 per cent, which is a very important matter in a local service with frequent stops.

Gearless motors have not been used to any extent for motor cars, as they are expensive and heavy for a given output, have injuriously heavy weights below the springs, and interfere with proper truck design. Common practice uses single-reduction geared motors.

It is usual to equip each motor car with two motors on one truck, the remaining truck being a trailer. Where cars are light, trains are quite generally made up of motor and trailer cars to the limit of the motor capacity in a given service; three-fifth motor to two-fifth trailer cars is common practice in mixed trains. As the weight of the cars has increased, it becomes necessary to make each car in a train a motor car; this incidentally, is of advantage in the more flexible distribution of equipment, and conduces to facility in making up trains.

Alternating current single-phase car-motors have been developed but practically no experience has been had with them except on single cars; if, however, the single phase system is to come into successful use for local service, they must be employed. According to the present design, these single-phase motors are somewhat larger, weigh more for a given output, and are somewhat less efficient than the best direct current motors; they also have a higher speed-characteristic and thus require a greater gear reduction for the train speed conditions of local service. Considering the relative weight of a complete electric equipment, motors and control, it has been estimated that for the particular case of a suburban multiple unit service with heavy cars, a 15 cycle 11,000 volt single-phase equipment weighs about 50 per cent more than a D. C. equipment of the same capacity, and corresponds to an increase of about 12 per cent in total car weight for a heavy single-phase car over the weight of a similar capacity direct current motor car.

Motors for electric locomotives are susceptible of special treatment and have been developed along somewhat different lines, as will appear later.

Motor control. — The " multiple unit " system of control is in universal use for heavy motor cars, when used either singly or in trains, and while the apparatus is complicated, bulky, heavy and costly, in actual operation it has been found extremely reliable. Two systems are in general use, the " Sprague-General Electric ", a purely electric control system, and the Westinghouse " Electro-Pneumatic " which, as its name indicates, employs compressed air and electricity. Both systems work well and both have been adapted for use with both alternating and direct current motors.

Electric locomotives. — Electric locomotives for heavy service are still in the development stage; much has been done towards perfecting their design, but much remains to be done before the questions of their design and practical performance

reach the stage of accumulated knowledge which we possess of these elements in steam locomotives. In the earlier stages of the art, attention was mostly directed to the perfection of electric apparatus; the importance of the mechanical features of the machine in its adaptation to track conditions, swere not fully appreciated. In fact, it was assumed that the characteristics of rotary motion and uniform torque, possessed by an electric motor, made it sapplication to a locomotive a simple matter, and removed one of the chief defects of a steam locomotive, the unbalanced reciprocating weights and unsymmetrical turning effort, which were held to be destructive to track. Experience has taught, however, that there are other elements in a locomotive which may be even more destructive, namely, unduly low center of gravity and improper weight and wheel base distribution. Defective design in these respects becomes especially noticeable in a machine where power is applied with extraordinary compactness, and where the machinery for its development is naturally centered around the driving axles, and the weight concentrated below the wheel tops. It appears to be a fact that in present designs of electric locomotives, a given total weight and individual wheel weight is more destructive to track than the same weight distributed as in steam locomotives. It is noticeable in motor cars even, that the quite moderate axle weights of a motor truck have an unfavorable effect upon economy in track maintenance.

The importance, therefore, of a study of the electric locomotive problem from standpoints other than that of power development, is being recognized and the co-operation of practical railway men in the design is being sought.

The first electric locomotives were practically powerful motor cars; that is, single-reduction motors were mounted on bogie trucks and carried a body and cab for housing the control apparatus. Then steam locomotive design began to be copied in the use of rigid frames carrying at times four axles and motors, and gearless motors of large capacity and great weight were employed. In the greater number of the earlier designs all weight was adhesive for driving — af eature which was supposed to constitute one great advantage of an electric over a steam locomotive.

These heavy and powerful locomotives at high speed began to manifest their bad riding qualities, and they were suspected of being " hard on track ". In order to bring out the facts experimentally, the Pennsylvania Railroad Company, who were about to design locomotives for their tunnel entrance into New York City, constructed a special test track with apparatus for measuring side pressures upon the rail; they built sample locomotives of different designs and instituted a series of tests of electric and steam locomotives to determine their relative riding qualities at speed. It is not the purpose of this report to go into the results of these tests in detail, but some of the more important conclusions may be stated in general as having a bearing upon the radical departure determined upon in design of their high speed electric locomotives.

It was found that all types of locomotives were practically steady at speeds under

40 miles per hour, but that above this speed marked differences appeared; that the steadiest riding machines were those with high center of gravity and with long and unsymmetrical wheel base. In other words, that the nearer steam locomotive design is approached in wheel arrangement, distribution of weight, height of center of gravity and ratio of spring-borne to under-spring weight, the less the side pressures registered on the rail head.

In addition to the excessive side pressures on the rail head, due to the oscillation and " nosing " of a low centre of gravity machine, abnormal track effects may be caused by the vertical pounding due to a large non-spring-borne motor weight, or to weights with imperfect spring cushion. A remedy for all of these defects appears to mean a radical departure in the design of a high speed locomotive, both as to its running gear and as to the form of motor drive. It means a combination of driving and carrying wheels, an unsymmetrically disposed wheel base and the setting of the motors on the main frames above the axles. The extent of the departures in practice thought desirable for heavy high speed locomotives, is shown in the diagrams and photographs of the Pennsylvania locomotive. It will be noted that it is a " double locomotive ", the halves being permanently connected, with the wheel arrangement of two " American " type steam locomotives (4-4-0) set back to back. Each half locomotive has a single very large gearless motor, set on top of the frames and driving through connecting rods to a jack shaft and thence by main and parallel rods to the wheels. The main features of this design may also be worked out by combining motor gearing with rods and with economy in motor cost on a slow-speed locomotive, but it was thought that the purely rod-drive was more suitable for high speed service. It will be interesting to observe from the diagram its similarity to a steam locomotive in the height of center of gravity and the ratio of spring-borne to non-spring-borne weight.

First cost.

It is difficult, in fact, practically impossible to give any general statement of the first cost of electrification which can be safely applied to individual cases. In the case of an entirely new line, built for traction by electricity, unit costs may be made to apply, but in the case of conversion of an existing steam line there are many collateral costs to be considered aside from those of electric equipment. In few cases will an electrified steam railroad be conducted precisely in the same manner as that previously done by steam; that is to say, multiple unit train service at frequent intervals will displace part or all of the infrequent locomotive train service; existing tracks, yards and terminals, stations, signalling, and telegraph lines must be changed to a greater or less extent to adapt the road to the new class of service; special rolling stock must in part be purchased and in places new real estate acquired.

It therefore results that each electrification must be dealt with as a separate and

individual problem and cost figures for one situation will generally not apply to another, even if the other road is of similar character. Generally speaking, the cost of converting a steam railroad is very high under American conditions, taking into account the changes in the physical property and equipment it will at times mean a doubling of the existing capitalization.

The high cost of conversion will act as a deterring factor upon additional electric construction until a sufficient number of installations are made to furnish evidence of the advantages and economy of electric traction; in fact, railway managers although watching closely, and with interest, the pioneer installations of electric operation on steam roads have not been anxious to duplicate experiments in advance of a demonstration of the results, and are awaiting this demonstration.

As elsewhere stated, the systems available for heavy traction are the A. C.-D. C. and the straight A. C., either single phase or polyphase. Comparative first cost figures for these two systems would be interesting, but are available only from estimates for the reasons before given and because of the fact that the systems are not in the same stage of development; thus, figures of cost for A. C.-D. C. would be more exact than in the case of the single phase because figures for the latter system must be made on assumptions of present methods of application, and these methods are, it is thought, susceptible to important modifications.

Considering the electrical items of installation, the chief elements of cost may be grouped under three headings; the power house, the transmission system from power house to the cars, and the train equipment.

Of these three divisions, in general the power house is the least expensive and the train equipment the most. For illustration, and comparing figures for the two systems, an estimate may be given of the case of a trunk line road with dense suburban traffic conducted by multiple unit trains and with an important through business conducted by electric locomotives. The percentage of the total electrical cost carried by the three equipment divisions were as follows :

	A. C.-D. C. system.	A. C. system (single phase).
Power-house	23 per cent.	25 per cent.
Transmission, power house-house to cars	35 —	22 —
Train equipments	42 —	53 —
	100 per cent.	100 per cent.

These percentage figures are given to show the relative importance, as regards cost, of the three divisions for the two systems, and shows the larger proportion carried by the train equipments of the single phase system.

The actual money value of the various costs would not be useful without a detailed presentation of the case, but the important fact developed was that there was little difference figured for the total first cost of either system, in other words, as at present developed, it appears that for a dense suburban service conducted by multiple unit trains, or, in the case of locomotive haulage in terminals or over short lengths

of a main line, there would be little difference in first cost between third rail A. C.-D. C. system and the single phase alternating current system; in fact, the figured differences are so small as to be within the limits of error in calculation. As, however, the length of line increases and as the frequency of trains becomes less and the weight of the trains increases, the single phase system becomes cheaper in comparison with the A. C.-D. C. and a substantial saving in first cost can be effected by the use of single phase on such lines. In fact, for long trunk line work and with the average density of traffic found on American railways, the first cost of the A. C.-D. C. system would certainly be prohibitive, whereas there will be found instances where this will not be the case with the alternating current system. It is, of course, a matter of importance to determine the prospect of reducing first cost. This might be accomplished by lowering in price of apparatus, or by a radical change in system, or by both. There appears to be a reasonable prospect of some substantial reduction in the first cost of electric apparatus, as the market for same broadens, but the manufacturers do not promise very radical reductions. As to the prospect of a change to a system inherently simpler and cheaper than existing ones, it would be unprofitable to predict what the future may bring forth; a system which would eliminate the element of transmission, power house to cars, would seem to open up a prospect of important simplification and cheapening, but such a system does not appear to be in process of development.

Cost of operation.

This is a matter of the highest importance to railway officials, since the question of net yield is the foundation for an investment. High first cost may act as a deterrent in the rapid introduction of an improvement, but in the end a new system will prevail if the operating results, as measured by the net earnings, show a betterment. Under another heading, will be given a summation of the advantages of electric traction and a statement of its probable field, but it is here proposed to give such concrete examples of operating costs as are available to the writer. It is to be regretted that the list is not longer, but it includes, perhaps, the only cases in which important installations have been in complete operation for a long enough period to furnish comprehensive figures.

The installations referred to are those on the Long Island Railroad and the West Jersey & Seashore Railroad, and figures are presented for two complete years' operation in each case.

Below are condensed tabular statements, taken from the complete monthly and yearly tables, of the figures which can be usefully given without lengthy explanation. They may be referred to as follows :

Table 1 gives a concise statement of the comparative physical characteristics of the electric installations on the two roads, from which a general idea of the magnitude of the operation may be gathered.

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Table 2 gives average number of cars in trains and the average weight per car. It will be noted that the average weight per car changes slightly in the two years, due to a change in the ratio of the motor to trailer cars.

Table 3 gives comparative figures for electrical quantities and efficiencies and is of interest in showing the distribution of the various losses in electrical energy from the power house to the cars. The figures for power consumption per ton-mile and per car-mile represent fair averages for electric installations of the character in question and in a climate which requires a considerable consumption of energy in winter for heating the cars. Electric heating adds very largely to power consumption, as will be illustrated when it is stated that, in summer months, the watt-hours per ton-mile at substations on the West Jersey & Seashore Railroad were about 63, while in mid-winter months this figure rose to 100; the larger part of this difference is due to the additional energy required to light and heat the cars in winter. It is interesting to note also that the efficiency of the electric system from the power station to the point where the current leaves the substation for feeding into the third rail is from 70 to 80 per cent, depending upon the loading during the various months; in the busy months, the efficiency will at times run as high as 85 per cent. The losses from the substation to the cars in the direct current feeder system cannot be accurately measured, but in the cases cited it is estimated to be between 5 and 10 per cent. The figures given for "current used for other purposes" illustrate the considerable and useful consumption of power for running shop motors, lighting stations and operating the signal system.

Table 4 gives the cost of generating current at the power house and cost of the current when delivered at the cars. The former figures include all power house operating and maintenance expenses, but no fixed charges, taxes or depreciation charges. The "delivered cost" includes the operating and maintenance cost for transmission lines, third rail, track bonding, and substations, and allowances for losses in transmission of the current and its conversion to direct current delivered at the car contact shoes. It should be noted, however, that the above figures do not include any maintenance expenses other than for electrical apparatus, and no portion of the general expenses of the railroad.

Table 5 gives the monthly car mileage and cost per car-mile; the total yearly mileage and the average car-mile cost; and average yearly cost per 1,000 ton-miles moved. The cost per car-mile includes the following: The cost of power, maintenance of third rail and track bonding, maintenance of car bodies and trucks, maintenance of way and equipment expenses, conducting transportation and traffic expenses, general expenses, wages of motormen and train crews; in fact, all operating expenses of the railroad. In comparing the costs per car-mile, the difference in weight of cars, given in table 2, should be noted; it should furthermore be explained that in the case of the Long Island Railroad, all trains may be termed "local" as the average length of the run on the so-called express service is only about 2 $^1/_2$ miles, whereas on the West Jersey & Seashore Railroad about

one-third of the total train-miles are made in cross-country express service with an average length of run of about twenty-five miles between stops, and the remaining service termed " local " averages 2 $^{1}/_{2}$ miles between stops, or about the same as express service on the Long Island Railroad. In other words, the Long Island installation may be considered purely local service in a densely populated district, whereas the West Jersey service approximates main line railway conditions with long runs.

Table 6 gives a list of the principle defects reported, and is of interest in showing which portions of train equipment require the largest amount of attention. The item for blown fuses appears excessively large, but it should be remembered that the purpose of these fuses is to guard against excessive current in the various critical portions of the equipment, and the fuses are purposely adjusted so as to be blown under exceptionally severe conditions; they are easily and quickly replaced by the train crews and cause little delay to service. The excessive number of fuses blown on the Long Island Railroad in 1908, was partly due to the use of stock fuses which were found somewhat too small for the increased requirements due to heavy loads and increased severity of service in that year. The considerable number of flash-overs of motors on the Long Island Railroad, was also largely due to very severe local service. Breakage of contact shoes is almost entirely due to striking material left by trackmen in the path of the shoes, but occasionally shoes are broken in striking the approach blocks where the third rail is interrupted at street crossings. It will be noted that there were a large number of defective trolley poles reported on the West Jersey & Seashore Railroad; this is due to the use of wheel trolleys and the ordinary type of cross-span overhead trolley wire; it illustrates, that while this type of construction was installed in the best manner, it is not suitable in practical service with trains of three or more cars operating at fairly high speed.

Table 7 classifies the principal detentions of all kinds due to electric equipment and gives the total train minutes of delay due to same. It also gives the totals reduced to figures of " car-miles per detention " and " car-miles per minute of detention ". In compiling this table detentions due to collisions and derailments have been omitted, as having no direct bearing upon the behaviour of electric equipment.

General remarks upon tables. — As before stated, the two roads have been in operation for a sufficiently long time to rather definitely establish the behaviour of all apparatus in practical service; there is no indication that in subsequent years of operation there will develope cause for extraordinary maintenance in any particular items due to the accumulative effect of service. It should be noted, however, that no account is taken of possible advances in the electric art, which might make the equipment obsolete; in other words, no " depreciation " account has been kept. In a rapidly advancing art, replacements on account of " change of type " are quite possible contingencies, but much difference of opinion exists upon this whole

Table 1. **Statistics.**

—	*Long Island Railroad.*		*West Jersey and Seashore Railroad.*
	1907	1908	1907-1908
Route miles of track	37·6	43·9	74·6
Miles of single track	90·0	98·69	152·5
Miles of high tension pole line.	41·0	42·0	69·59
— — — circuit (3-phase)	70 24	80·03	417·54
— — — — (1-phase)	14·1	9·7	None.
— of conduit.	9 09	9·09	...
High tension transmission voltage	11,000	11,000	33,000
Number of substations	6	6	8
— of portable substations	2	2	None.
Capacity of substations	19,500	19,500	17,000
— of portable substations	2,000	2,000	None.
— of power house.	16,500	16,500	8,000
Number of motor cars	130	132	80
— of trailer cars	84	82	None.
— of baggage and mail cars	5	5	8

Table 2. **Weight of cars and make-up of trains.**

—	*Long Island Railroad.*		*West Jersey and Seashore Railroad.*	
	1907	1908	1907	1908
Average car per train	3·70	3·94	2·95	3·45
Average tons per car (1 ton equals 2,000 lbs.)	37·8	36·5	47·9	47·4

Table 3. **Energy consumption.**

—	1907		1908	
	Long Island Railroad.	*West Jersey and Seashore Railroad.*	*Long Island Railroad.*	*West Jersey and Seashore Railroad.*
1. A. C. kilowatt-hours received at substations	20,341,826	...	21,899,739	...
2. Efficiency of H. T. transmission	96·2	...	97·7	...
3. D. C. kilowatt-hours delivered from substations	16,138,965	14,585,900	18,138,515	16,088,300
4. D. C. — used for electric traction.	13,466,995	13,530,659	16,201,962	14,780,145
5. D. C. — used for other purposes	896,075	389,672	901,934	731,771
6. Kilowatt-hours lost in conversion from A. C. to D. C.	4,202,861	5,882,510	3,761,224	5,997,020
7. Efficiency from power house to substation bus-bars	78·52 per cent.	72·15 per cent.	81·3 per cent.	73·8 per cent.
8. Total ton-miles-passenger	141,541,106	184,615,535	180,129,860	192,472,541
9. Car-miles-passenger.	3,808,479	3,855,580	4,945,719	4,044,025
10. Train-miles-passenger	1,021,102	1,305,663	1,251,877	1,172,894
11. Watt-hours per ton-mile at substations	95·2	73·29	90·0	76·8
12. — — — at power house	121·2	101·58	110·6	104·0
13. Kilowatt-hours per car-mile at power house	4·51	4·86	4·028	4·95
14. — — — at substation	3·54	3·51	3·276	3·66

Table 4. **Current and maintenance costs.**

—	*Long Island Railroad.*		*West Jersey and Seashore Railroad.*	
	1907	1908	1907	1908
Cost per kilowatt-hour at power house	0·804 cents.	0·697 cents.	0·680 cents.	0·592 cents.
— — at cars	1·705 —	1·461 —	1·302 —	1·151 —
Cost per car-mile for maintenance of electrical equipment on cars	0·71 —	0·76 —	...	...
Net output in kilowatt-hours at power house	...	31,517,200	...	22,887,800
Lb of coal per kilowatt-hour	...	3·29	...	3·36
Cost of coal per ton : 2,000 lb.	...	2·512 dollars.	...	2 1814 dollars.
Number and capacity of units	...	Three : 5,500 kilow.	...	Four : 2,000 kilow.
Total kilowatts capacity of power house	...	16,500 —	...	8,000 —

Table 5. **Car-mile costs.**

MONTH.	CAR-MILES.				COST PER CAR-MILE.			
	West Jersey and Seashore Railroad.		*Long Island Railroad.*		*West Jersey and Seashore Railroad.*		*Long Island Railroad.*	
	1907	1908	1907	1908	1907	1908	1907	1908
					Cents.	Cents.	Cents.	Cents.
January	294,672	281,723	235,828	201,128	27·50	29·29	28·16	26·97
February	255,344	271,542	214,242	186,256	30·90	28·53	30·04	27·87
March	270,286	291,959	241,024	224,919	23·90	26·57	28·05	24·77
April	244,431	331,224	281,509	271,224	24·30	21·34	24·05	23·94
May	267,317	323,584	347,211	382,195	21·50	19·97	21·39	20·90
June	292,767	344,523	349,133	478,793	22·50	18·92	22·32	18·00
July	435,860	451,149	392,514	628,511	15·30	16·17	15·73	13·53
August	478,041	485,565	400,880	632,388	14·90	13·71	15·59	13·26
September	411,359	369,204	299,798	509,213	15·85	17·17	19·87	14·79
October	317,141	312,833	306,138	441,638	23·50	19·55	22·37	17.21
November	292,349	282,322	245,748	345,640	21·40	20·42	25·93	22·29
December	295,097	292,397	212,144	360,325	22·60	22·68	27·48	22·45
TOTAL	3,854,664	4,044,025	3,526,227	4,662,230	21·30	20·46	22·45	17·80
Cost per 1,000 ton-miles	...	...	...	...	$ 4·406	$ 4·307	$ 5·94	$ 4·86

Table 6. **Defects of train equipment.**

	1907		1908	
	Long Island Railroad.	*West Jersey and Seashore Railroad.*	*Long Island Railroad.*	*West Jersey and Seashore Railroad.*
Flash-overs	23	None.	42	1
Main fuses blown	50	.	60	...
Shoe fuses blown	1,169	844	4,812	1,934
Trolley fuses blown	None.	358	None.	711
Bus fuses blown	158	51	182	169
Controller fuses blown	None.	138	None.	118
Heater & pump fuses blown	379	359	590	383
Total fuses blown	2,023	1,955	6,028	3,504
Hot motor axle bearings	6	8	25	2
Hot journal bearings	6	44	34	28
Grounded armatures	9	6	27	6
Short circuited armatures	1	In above.	9	In above.
Grounded fields	1	2	2	1
Commutators	5	None.	16	None.
Contact shoes replaced	500	925	672	564
Pump motor armatures	10	1	15	2
Control	86	180	139	99
Brake equipment	15	40	26	15
Short circuits (miscl.)	5	..	9	...
Trolley poles	Not used.	981	Not used.	469

Table 7. **Delays due to electric equipment.**

—	1907				1908			
	Long Island Railroad.		*West Jersey and Seashore Railroad.*		*Long Island Railroad.*		*West Jersey and Seashore Railroad*	
	No.	Train. Minutes.	No.	Train. Minutes.	No.	Train. Minutes.	No.	Train. Minutes.
Motors.	13	197	21	404	35	270	20	134
Control equipment	21	286	180	2,209	72	644	99	509
Air brakes	8	84	40	247	38	428	14	54
Miscellaneous mechanical equipment	7	74	80	1,073	57	964	45	427
— electrical equipment.	58	1,006	316	1,564	44	781	183	693
Failures of power due to 3rd rail	17	218	8	103	36	792	3	47
— — — to trolley	...	...	86	1,122	...	...	223	3,498
— — — to S.-S. & Trans	5	25	13	80	31	190	36	284
Track troubles	7	263	7	146	1	15	1	18
Snow and ice on 3rd rail	8	161	72	1,751	16	244	9	69
Shoe fuses blown	...	...	...	...	107	1,881	...	...
Unclassified and unknown	15	179	120	844	53	552	27	108
TOTAL.	159	2,493	943	9,543	490	6,761	661	5,841
Car-miles (passenger & baggage)	3,526,227		3,855,580		4,662,230		4,044,025	
— per detention	22,177		4,088		9,514		6,118	
— per minute of detention	1,414		404		689		692	

subject in America and its pros and cons cannot be entered into in this general report.

Of the total cost per car mile, one third is due to cost of supplying power to the car, including maintenance of all parts of the electric system on the car, and of this figure about one half is the cost of the power alone. In both roads, the load conditions at the power houses are not favourable, nor is the quantity of power turned out as large as it is expected to be in the near future, so that the item for cost of power at the car should come down considerably as the magnitude of the operation increases. Other items also in the total cost per car mile, namely, general expenses of various kinds and wages of motormen and train crews, are largely affected by density of traffic and have a downward tendency.

The list of detentions looks quite formidable, but when analysed the general result is found to be good. Motors, as before stated, have been brought to a high state of perfection and detentions caused by their failure on the road are rare and largely due to overloading. The temptation in electric service is constantly to overload, either quickening the schedule, increasing the number of stops or adding trailer cars; this is due to the fact that the apparent limit of capacity of railway motors is their ability to make schedule and it is often not remembered by the railway superintendent that this is far beyond the heating capacity of the motors.

Where all cars in a train are motor cars, overloading cannot be as readily accomplished as where trailers are hauled, especially if the motors have been designed to take care of a continuous running condition with the minimum number of stops, as is generally the case.

The multiple unit control system is a very complicated assemblage of delicate apparatus, but works surprisingly well and when properly maintained it will be noted gives very little trouble.

Table 6 is confined to the statement of delays and troubles on the train equipment; but in table 7 the troubles due to the other parts of the electric installation, namely, the third rail, transmission lines, substations and power house, are included and it is interesting to note the unavoidable delay caused by these features of an electric installation.

Cost compared with steam.

Considering the figures for the year 1908, it is seen that the Long Island road operated their electric mileage at a cost of 17·80 cents per car-mile; the steam train mileage cost 27·95 cents, a difference in favour of electric traction of 10·15 cents per car-mile. On the West Jersey & Seashore Railroad, the electric mileage cost 20·46 cents per car-mile as against 22·30 cents for the steam mileage, or a saving for the electric service of 1·94 cents per car-mile.

The relatively unfavourable showing on the West Jersey for electric saving is in part accounted for by the difference in character of the service on the two roads, as before explained, and by the fact on the Long Island road the average length of

train in steam service was about the same as in the electric and the stops frequent; it was, therefore, costly service. On the West Jersey the average cars per steam train was twice that of the electric and much of the service was long distance express with few stops and of an exceptionally economical character.

Operating costs of A. C.-D. C. vs. A. C.

A comparison of this kind must at present writing be based on estimates and opinion, as no operating figures for the A. C. systems are obtainable. It is the opinion of the writer that the maintenance costs of the single phase system, as at present developed, will be somewhat higher than for the A.C.-D.C., but not by an important amount; eventually the maintenance costs should be about the same for either system. The total operating cost figure, however, will probably be in favor of the single phase system, because of the higher average efficiency of this system and the lower operating cost of substations. The importance of the savings possible for the single phase will depend upon the character and extent of the traction scheme, becoming greater as the length of line increases and the density ot traffic decreases. It is impossible, however, to generalize safely and each case should be considered upon its own merits.

An estimate may be given for the particular case referred to under the " first cost " heading, in which it was figured that about 13 per cent less energy at the power house would be required for the single phase than for the A.C.-D.C. system. This, together with the saving in substation operation, would show an operating saving of about one cent per car-mile, or, say, between 4 and 5 per cent, of the total operating cost.

APPENDIX A.

Synopsis of important installations.

Below will be found, in chronological order, a brief description of the more important installations to date of heavy electric traction, and in Tables 8 and 9 are given further details of the systems.

Baltimore & Ohio Railroad. — An example of special terminal electric operation, conducted primarily for the purpose of smoke elimination in a long tunnel. Service was inaugurated in 1895 through the tunnel entrance into the Mt. Royal Station of the Company in the City of Baltimore. The method of operation is to haul the entire train, steam locomotive included as a trailer, by an electric locomotive. As the ruling grade through the tunnel is in one direction only, the trains are assisted only in the up-grade direction, and the electric locomotives usually return light; trains in the opposite direction drift through the tunnel.

The system is " direct current " at 625 volts, and as originally constructed the working conductor was in the form of an overhead " Z " bar. This form of conductor was, however, soon abandoned in favour of a third rail set near the track, as the overhead conductor was found to corrode rapidly because of the presence of steam locomotives, and sparkless contact could not be maintained. Both freight and passenger trains are hauled through the tunnels and into the terminal station by means of electric locomotives, of which they have at present an equipment of eight.

The locomotives have been purchased from time to time, as required by the growth of traffic, and consequently a number of types are in use. The passenger locomotives (See diagram 1 [fig. 14]) weigh about 96 tons and are equipped with four gearless motors, each locomotive being capable of exerting a maximum draw-bar pull of 48,000 lb. The freight locomotives (see diagram 2 [fig. 15]) weigh about 80 tons per unit and are used as double units on the heavier grades, and have a maximum draw-bar pull of 80,000 lb.

The power house is equipped with five 500 kilowatts 625-volt direct current generators coupled to non-condensing engines, and storage batteries are used as an auxiliary. Because of the local conditions and the pioneer character of the apparatus, the operating costs are high.

Long Island Railroad. — In 1905 the Long Island Railroad Company began electric operation on a portion of their lines. It was the first suburban passenger railroad to electrify, and the portion so operated is still one of the most extensive in the country; the electrification will shortly be greatly extended by additions made necessary to operate through the Pennsylvania tunnels into the New York City passenger terminal.

Primarily, the electrification was undertaken in connection with the " Atlantic Avenue Improvement ", which consisted in the elimination of numerous grade crossings in the Borough of Brooklyn (New York City) and the reconstruction of about nine miles of surface road to a subway and elevated railroad construction. These improvements made necessary the elimination of steam locomotives on this particular line, and, furthermore, in order to make a practical

Table 8. **General characteris**

—	*Baltimore and Ohio Railroad.*	*Long Island Railroad*
General.		
Classification	Terminal.	Suburban.
Date placed in operation	1895	July 1905.
System of traction	Direct current.	Direct current (A. C.-D. C.).
Mileage : route	3·7	43·9
— track	8·4	110·0
Maximum grade in per cent	1·4	2·0
— curve	10°	9°
Conductors.		
Type of working conductors, voltage, position, etc.	Over running 3rd rail, 500 volts.	Over running protected 3rd rail, 65
Power stations.		
Number of power stations and type	One : Steam.	One : Steam.
Rated capacity of each	2,500 kilowatts.	16,500 kilowatts.
Number of generators installed in each : rating and type	Five : 500 kilowatts 625 volt, direct current.	Three : 5,500 kilowatts, 11,000 vol 3-phase, 25-cycles.
Type of prime mover	Non-condensing engines.	Steam turbines.
Boilers : number per station, type, rating of each	Thirty-three : Water tube. 250 horse-power.	Thirty-two : Water tube. 524 horse-power.
Fuel consumption : lb. per kilowatt-hour	...	3·29
Evaporation : lb. water per lb. coal	...	7·83
Ratio boiler horse-power to generator horse-power	0·94	(See Pennsylvania Railroad New Tunnel Extension.)
H. T. transmission and substations.		
Feeders : mileage and type	None.	70·4 miles overhead circuits 26.5 miles underground ; 11,000 v
Substations : number, capacity of each, average distance apart	None.	Eight : 2,000 to 4,500 kilowatts; 2 1/2 miles apart.
Capacity of rotary converteor units	None.	1,000 and 1,500 kilowatts.
Rolling stock.		
Locomotives or cars used	Locomotives.	Multiple unit trains.
Number and type of epuipment	5 freight, 3 passenger locomotives.	134 motor and 84 trailer cars
Make-up of trains	Freight, 1,300 tons. Passengers, 250 tons, trailing load but exclusive of steam locomotive which is kept on trains.	Average, 3·95 cars; maximum, 10
Locomotives : weight in tons	Passengers, 96; freight, 80.	...
Number of motors per locomotive	4	...
Capacity per motor : 1 hour rating	...	...
Tractive effort, per locomotive at starting, in lb.	Passengers, 48,000; freight, 40,000.	...
— — at rated load, in lb.	Freight, 38,000.	...
— — at maximum speed on level, in lb.	...	...
Motor cars : weight exclusive passengers	...	83,800 lb.
— — seating capacity	...	52
— — number of motors	...	2
— — rated capacity per motor	...	200 horse-power.
Tractive effort : per car at starting, in lb.	...	6,800
— — rated load, in lb	...	6,000
— — maximum speed on level, in lb	...	800 at 48 miles per hour.
Trailer cars : number per train	...	1 trailer to 2 motor cars.
Weight and seating capacity	...	39,000 lb. ; 56 passengers.
— per driving axle, in lb.	Passengers, 48,000; freight, 40,000.	29,000
— per truck axle, in lb.	...	16,400
Schedule speed in miles per hour	Passengers, 20; freight, 10.	Local, 22; Express, 30.
Average distance between stops-miles	...	Local, 0·9 to 1·2; Express, 2 1/2 av

nportant installations. **Table 8.**

Pennsylvania Railroad st Jersey and Seashore Railroad.	*New York Central and Hudson River Railroad.*	*Erie Railroad.*
Main line express and local. September 1906. Direct current (A.C.-D.C.) 74·6 162·7 3·0 12°-30′	Terminal. December 1906. Direct current (A. C.-D. C.) 22·5 101.0 1.25 6°	Suburban June 1907. A. C. Single-phase. 33 38 0.94 5°-44′
running unprotected 3rd-rail, 650 volts; also 13·7 miles cross-span trolley.	Under running protected 3rd rail, 650 volts.	Single catenary wooden pole and bracket arm construction. Trolley 21 feet, from rail. 11,000 volts.
One : Steam. 8,000 kilowatts. 2,000 kilowatts, 6,600 volts, A. C. 3-phase, 25 cycles. Steam turbines. Sixteen : Water tube. 358 horse-power 3·36 7·96 0·53	Two : Steam 20,000 kilowatts Four : 5,000 kilowatts, 11,000 volts A. C; 3-phase, 25 cycles. Steam turbines. Sixteen : Water tube. 625 horse-power. 2·5 8·0 0·374	Power purchased from Niagara Falls Water Power Co. Transmitted 72 miles to railway line.
head 3 phase lines; 130 miles of circuit; 33,000 volts. including one in power house; 1,000 to 00 kilowatts average, 9-1/2 miles apart. 500, 750 and 1,000 kilowatts.	18·5 miles overhead circuit; 58·5 miles underground; 11,000 volts. Five : 3,000 or 4,500 kilowatts, 4 to 6 miles apart. 1,000 and 1,500 kilowatts.	Overhead, 60,000 volts, 144 circuit miles. None None
Multiple unit trains. 89 motor cars. Average, 3 cars; maximum, 8 cars.	Locomotives and multiple unit trains. 47 locomotives, 125 motors and 55 trailers. Average, 4 cars; maximum, 10 cars.	Multiple unit trains 6 motor cars. Average, 2 motor cars; maximum, 2 motor cars and 2 trailers.
... ... 89,000 lb. 58 2 200 horse-power. 4,500 ... 1,050 at 50 miles per hour. None. ... 26,850 17,050 Local, 30; express, 45. Local, 1.37; express, 22.	95 and 115 4 550 33,500 and 35,500. 23,000 5,050 with 435 tons trailing load. 100,000 lb. 64 2 200 horse-power. 6,200 5,050 716 at 52·3 miles per hour. 1 trailer to 2 motor cars. 88,000 lb.; 64 passengers. Locomotives 33,500 and 35,500; cars, 30,000. Locomotives 28,000 and 22,000; cars, 23,000. Local, 21 to 24; express, 28 to 29. Local, 1·05 and 1·45; express, 7·25 and 12·56.	... ... 96,000 lb. 6 4 100 horse power. ... ... None. ... 24,000 ... 35 2·84

Table 9. **General characteristi**

—	*New York, New Haven and Hartford Railroad.*	*Spokane and Inland Railroa*
General.		
Classification	Main line expres s and local.	Main line freight.
Date placed in operation	July 1907.	1907
System of traction	A. C. Single-phase.	A. C. Single-phase.
Mileage : route	21·5	135
— track	100 0	135
Maximum grade in per cent	0·57	2·0
— curve	3°-5'	10°
Conductors.		
Type of working conductors, voltage, position, etc.	Double catenary with steel working conductor; copper secondary trolley. Trolley 22 feet from rail. 11,000 volts.	Single catenary wooden poles with b ket arms. Trolley 22 feet from 6,600 volts.
Power stations.		
Number of power stations and type	One : Steam.	One : Hydro-electric.
Rated capacity of each	15,500 kilowatts.	15,000 kilowatts.
Number of generators installed in each : rating and type	Three : 3,750 and 1 : 4,250 kilowatts, 11,000 volts A. C., 3-phase, 25 cycles.	Three : 5,000 kilowatts, 6,600 volts, A 3-phase, 60-cycles.
Type of prime mover	Steam turbines.	Hydraulic turbines.
Boilers : number per station, type, rating of each	Twelve : Water tube. 550 horse-power.	None.
Fuel consumption : lb. per kilowatt-hour	3·25	...
Evaporation : lb. water per lb. coal	8·5	...
Ratio boiler horse power to generator horse-power	0·318	...
H. T. transmission and substations.		
Feeders : mileage and type	Overhead conductor.	Overhead 3 phase lines, 180 miles circuit ; 45,000 volts.
Substations : number, capacity of each, average distance apart	None.	One frequency changing station ; tw transformer substations.
Capacity of rotary convertor units	None.	...
Rolling stock.		
Locomotives or cars used	Locomotives.	Locomotives for freight; mult. unit tra for passengers.
Number and type of equipment	41 locomotives.	9 locomotives; 24 motor and 12 trail cars.
Make-up of trains	Average, 240 tons ; maximum, 320 tons, trailing load, 1 locomotive.	Average, 2 cars; maximum, 5 cars
Locomotives ; weight in tons	100	Average freight, 350 tons trailing lo 6 at 50; 3 at 72.
Number of motors per locomotive	4	4
Capacity per motor : 1 hour rating	250 horse-power	50 ton locomotives, 125 horse-powe 72 ton locomotives, 170 horse-powe
Tractive effort, per locomotive at starting, in lb.	20,000	36,000
— — at rated load, in lb.	8,400	19,000 and 46,000.
— — at maximum speed on level, in lb.	...	...
Motor cars : weight exclusive passengers	...	94,000 lb.
— — seating capacity	...	...
— — number of motors	...	4
— — rated capacity per motor	...	100 horse-power.
Tractive effort : per car at starting, in lb.	...	...
— — rated load, in lb.	...	...
— — maximum speed on level, in lb.	...	...
Trailer cars : number per train	...	...
Weight and seating capacity	...	...
— per driving axle, in lb.	38,500	...
— per truck axle, in lb.	23,000	...
Schedule speed miles per hour	Local, 26; express, 37.	...
Average distance between stops-miles	Local, 22; express, 8 to 9.	...

N. B. — All tons of 2,000 lb. each.

nportant installations. (Continued.) **Table 9.**

rand Trunk Railway.	*Great Northern Railway.*	*Southern Pacific Railway.*	*Pennsylvania Railroad New York Tunnel Extension.*
Main line special service.	Main line special service.	Suburban.	Terminal.
April 1908.	July 1909.	1909	1910
A. C. Single-phase.	A. C. Single-phase.	Direct current (A. C.-D. C.).	Direct current (A. C.-D. C.).
3·8	4·0	...	12·0
12·0	6·0	...	75·0
2·0	2·2	1·0	1·93
7°·31′	None.	39°	9°
Special single catenary.	Cross span. Two overhead	Single catenary. Trolley 22 feet	Over running protected 3rd rail.
y 22 feet from track. 3,300 volts	conductors. 6,000 volts.	from rail. 1,200 volts.	650 volts.
One : Steam.	One : hydro-electric.	One : Steam.	One : Steam.
2,500 kilowatts.	5,000 kilowatts.	10,000 kilowatts.	16,000 kilowatts additional capacity
1,250 kilowatts, 3,300 volts,	Two : 2,500 kilowatts, 6,600 volt,	Two : 5,000 kilowatts, 13,200 volts,	to be installed in Long Island Rail
A. C. 3-phase, 25 cycles.	A. C. 3 phase, 25 cycles.	A. C. 3-phase, 25 cycles.	road station plus 6 000 kilowatts of
Steam-turbines.	Hydraulic turbines.	Steam turbines.	lighting units.
Four : Water tube.	None.	Twelve : Water tube.	Total capacity 38,500 kilowatts.
400 horse-power.		625 horse-power.	
7·8	...	1·5 oil fuel (est.).	
7·74	...	14 (est.).	
0·478	...	0·55	0·318
None.	Overhead; 64 circuit miles;	Underground 3-phase conductors,	Underground and overhead;
	33,000 volts.	13,200 volts.	48 miles of circuit.
None.	One : 5,000 kilowatts.	Two : 4,500 kilowatts, 5·5 miles apart.	Three : 6,000 kilowatts.
None.	None.	1,500 kilowatts.	2,000 kilowatts.
Locomotives.	Locomotives.	Multiple unit trains.	Locomotives.
5 locomotives.	4 locomotives.	44 motor and 40 trailer cars.	2 locomotives.
ht 1,000 tons, passengers, 150	2,200 tons trailing load, 3 locomotives	Average, 5 cars, maximum, 12 cars.	550 tons maximum for 1 locomotive.
to 600 tons, trailing load.	used.		900 tons maximum for 2 locomotives
65·75	115	...	165
3	4	...	2
225 horse-power.	475 horse-power.	...	1,250 horse-power.
000 on 2 per cent grade with	57,500	...	55,000
t. trailing load. (2 locomotives)	46,000	...	26,800
...	...	...	...
None.	None.	104,200 lb.	...
..	...	92	...
...	...	4	...
...	...	125 horse-power.	...
...	...	16,000	...
...	...	10,450	...
...	...	6,000 at 40 miles per hour.	...
...	...	1 trailer to 2 motor cars.	...
None.	None.	65,000 lb ; 92 passengers.	...
...	...	...	56,500
43,800	57,500	26,050	26,500
...	...	20 (est.).	Terminal service, 8·75 from start to
15·0	15		end of electric zone.
2·5	4·0	...	...

Table 10. General characteris

—	*Baltimore and Ohio Railroad.* — *Passenger.*	*Baltimore and Ohio Railroad.* — *Freight.*	*New York Central and Hudson River Railroad* — *Original.*	*New York Central and Hudson River Railroad* — *Revised.*	*Pennsylvania Railroad.* — *Experimental.*	*Pennsylv Railroa* — *Experime*
Key number for reference to diagrams and curves	1	2	3	4	5	6
General.						
Builder : Mechanical	American Locomotive Co.	American Locomotive Co.	American Locomotive Co.	American Locomotive Co.	Pennsylvania Railroad	Baldwi Locomotiv
Builder : Electrical	General Electric Co.	General Electric Co.	General Electric Co.	General Electric Co.	Westinghouse Company	Westingh Compan
Date built	1895	1903	1906	1908	1905	1907
Type	0-4-4-0	0-8-0	2-8-2	4-8-4	0-4-4-0	4-4-4-4
Number of driving wheels	8	8	8	8	8	8
Number of truck wheels	...	...	4	8	...	8
Number of motors	4-DC	4-DC	4-DC	4-DC	4-DC	4-AC sin phase.
Dimensions (1).						
Length over couplers	35′ 0″	29′ 0″	37′ 0″	43′ 0″	36′ 5″	65′ 8
Width of cab	9′ 5″	9′ 5″	10′ 0″	10′ 0″	10′ 2″	10′ 0
Height from rail to top of roof	14′ 3″	13′ 8″	14′ 4″	13′ 9″	13′ 4″	13′ 1
Driving wheel base	23′ 2″	14′ 7″	13′ 0″	13′ 0″	26′ 1″	30′ 0
Truck wheel base	6′ 10″	...	...	6′ 0″	8′ 6″	6′ 2
Rigid wheel base	6′ 10″	14′ 7″	13′ 0″	13′ 0″	8′ 6″	7′ 6
Total wheel base	23′ 2″	14′ 7″	27′ 0″	36′ 0″	26′ 1″	56′ 2
Diameter of driving wheels	62″	42″	44″	44″	56″	72
Diameter of truck wheels	...	...	36″	36″	...	36
Weights.						
Per driving axle, in lb.	48,125	40,000	33,500	35,500	48,785	54,90
Per truck axle, in lb.	...	...	28,000	22,000	...	21,15
Total, in lb.	192,6?0	160,000	190,000	230,000	195,140	304,00
Per foot of wheel base, in lb.	8,340	11,000	7,0?0	6,400	7,500	5,43
Center of gravity of locomotive	43·2″	40·5″	44·4″	40·0″	42·5″	55·0
Speed.						
Approximate with full load on level, in miles per hour	20	10	60	60	45	60
Power.						
Tractive effort at starting (2), in lb.	48,000	40,000	33,500	35,500	37,400	26,80
Tractive effort at 1 hour rating, in lb.	...	32,000	23,000	23,000	17,540	14,40
Tractive effort at cont. rating, in lb.	...	...	5,700	5,700	...	7,60
Motors.						
Type	DC No. AXB-70	DC No. GE-65	DC No. GE-84-A	DC No. GE-84-A	2 DC No. 103 2 DC No. 129	AC No.
Rating H.P. : 1 hour	180	200	550	550	300 & 320	46
Rating H.P. : continuous	....	...	230	230	...	31
Current per motor : starting	1,725	318	1,100	1,100	800	2,50
Current per motor : 1 hour	...	300	750	750	416 & 438	1,59
Current per motor : continuous	...	...	325	325	...	1,04
Voltage at collector	625	625	625	625	600	11,00
Voltage at motor	300 app.	625	625	625	600	27
Weight of each motor	...	12,975	11,500	11,500	11,500	19,50
Weight of each armature	9,500	2,800	7,640	7,640	5,300	9,35
Gear ratio	Gearless.	81 : 19	Gearless.	Gearless.	Gearless.	Gearless

(1) All figures under heading « Dimensions » have been given to nearest complete inch, neglecting fractions.
(2) Unless limited by characteristics of motors the starting tractive effort is calculated as one-quarter of the weight upon the driving wh

tric locomotives. Table 10

ylvania road. — enger.	New York, New Haven and Hartford Railroad. — Original.	New York, New Haven and Hartford Railroad. — Revised.	Spokane and Inland Railroad. — Freight.	Spokane and Inland Railroad. — Freight.	Grand Trunk Sarnia Tunnel — Passenger and Freight.	Great Northern Railway. — Freight.	Michigan Central Detroit River Tunnel. — Freight.
7	8	9	10	11	12	13	14
ylvania road	Baldwin Locomotive Works	Baldwin Locomotive Works	Baldwin Locomotive Works	Baldwin Locomotive Works	Baldwin Locomotive W.	American Locomotive Co.	American Locomotive Co.
ghouse pany	Westinghouse Company	Westinghouse Company	Westinghouse Company	Westinghouse Company	Westinghouse Company	General Electric Co.	General Electric Co.
09	1906	1908	1906	1907	1907	1908	1909
-4-4	0-4-4-0	2-4-4-2	0-4-4-0	0-4-4-0	0-6-0	0-4-4-0	0-4-4-0
8	8	8	8	8	6	8	8
8	...	4	...	...	...	8	8
DC	4-AC single phase	4-AC single phase	4-AC single phase	4-AC single phase	3-AC single phase.	4-AC 3-Phase	4-DC
11"	37' 7"	37' 7"	32' 1"	38' 3"	29' 4"	44' 2"	39' 6"
0"	9' 7"	9' 7"	9' 6"	9' 6"	10' 2"	10' 0"	10' 0"
1"	12' 2"	12' 2"	11' 9"	12' 2"	13' 0"	14' 2"	12' 4"
1"	22' 6"	22' 6"	21' 1"	24' 10"	16' 0"	31' 9"	27' 6"
7"	8' 0"	8' 0"	7' 4"	9' 6"	...	11' 0"	9' 6"
2"	8' 0"	8' 0"	7' 4"	9 6"	16' 0"	11' 6"	9' 6"
11"	22' 6"	30' 10"	21' 1"	24' 10"	16' 0"	31' 9"	27' 6"
68"	62"	62"	38"	50"	62"	60"	48"
36"	...	33"	...	...	...	...	...
,800	48,000	40,500	25,070	36,250	42,200-47,000	57,500	50,000
,400	...	20,000	...	...	...	...	...
,800	192,000	202,000	100,280	145,000	131,400	230,000	200,000
,870	8,540	6,530	4,750	5,830	8,200	7,220	7,280
75"	53·0"	...	...	...	51·0"	60·0"	42·5"
0	60	60	25	15	35	15	35
,000	AC 20,000 DC 24,000	AC 20,000 DC 24,000	AC 25,000 DC 25,000	AC 36,000 DC 36,000	43,800	57,500	50,000
,400	AC 8,400 DC 10,200	AC 8,400 DC 10,200	AC 10,500 DC 13,000	AC 22,000 DC 27,500	19,000	46,000	35,000
,000	AC 5,700 DC 7,750	AC 5,700 DC 7,750	AC 5,02 DC 6,000	AC 14,600 DC 15,500	11,800	36,000	...
o. 315	AC DC No. 130	AC DC No. 130	AC DC No. 133	AC DC No. 151	AC No. 137	AC No. GEI-506	DC No. GE-209-A
,250	AC 235 DC 360	AC 235 DC 360	AC 125 DC 94	AC 170 DC 150	225	475	275
800	AC 195 DC 295	AC 195 DC 295	AC 86 DC 60	AC 140 DC 108	178	375	...
,850	AC 2,025 DC 2,000	AC 2,025 DC 2,000	AC 960 DC 830	AC 1,125 DC 1,100	1,525	700	530
,725	AC 1,090 DC 1,000	AC 1,090 DC 1,000	AC 545 DC 543	AC 820 DC 910	910	500	400
,070	AC 845 DC 810	AC 845 DC 810	AC 365 DC 365	AC 645 DC 635	685	...	...
650	AC 11,000 DC 600	AC 11,000 DC 600	AC 6,600 DC 600	AC 6,600 DC 600	3,300	6,000	625
650	AC 220 DC 300	AC 220 DC 300	AC 235 DC 150	AC 220 DC 150	235	500	625
,000	16,710	16,710	6,025	10,420	15,660	...	...
,950	5,850	5,850	2,705	3,570	5,095	...	...
l drive.	Gearless.	Gearless	72 : 17	79 : 17	85 : 16	4·28 : 1	4·37 : 1

*

Table 11.

Electric and steam locomotives.

Comparison of weights and centres of gravity.

	ELECTRIC.				STEAM.	
Type	0-4-4-0	4-4-4-4	4-4 4-4	2-4 4-2	4-4-2	4-4-0
Railroad	*Pennsylvania Railroad.*	*Pennsylvania Railroad.*	*Pennsylvania Railroad.*	*New York, New Haven and Hartford Railroad.*	*Pennsylvania Railroad.*	*Pennsylvania Railroad.*
Reference to table 9	5	6	7	9	...	...
Service	Experimental.	Experimental.	New York Tunnel.	Main Line.	Main Line.	Main Line.
Total weight of locomotive in running order in pounds	195,140	304,000	332,000	202,000	176,600	138,000
Height of centre of gravity of complete locomotive from rail in inches	42.5	55	63.75	53	73	63
Percentage of weight of running gear below springs to total weight, including motors in the case of electric locomotives Nos. 5, 6 and 9	50 per cent.	46·3 per cent.	(1) 16·7 per cent.	37·4 per cent.	22·7 per cent.	22·7 per cent.
Height of centre of gravity of running gear from rail in inches	28	33·5	(1) 30·2	30	33	29

(1) Does not include motors as they are mounted in cab.

operating scheme of the "improvement" in connection with the suburban district served, it was necessary to extend the electrification to a number of the outlying lines, so that passengers could complete the journey throughout the suburban zone without transfer. This involved the conversion of about 44 route miles, equivalent to about 110 miles of single track.

Multiple unit car operation was adopted throughout as well as the use of all steel motor cars.

The third rail "A. C.-D. C." system of traction is used, power being supplied from a central station built by the Pennsylvania Railroad Company for the joint use of the Long Island Railroad and the new Pennsylvania Tunnel & Terminal Line. This power house was located centrally with reference to the eventual joint load which placed it eight miles from any of the Long Island lines initially electrified. Three-phase current at 11,000 volts is conducted from the power house in part by underground and in part by overhead transmission lines to a central point on the Long Island system, and thence to substations properly spaced for distribution to the third rail working conductor system.

The entire installation was carried out in a very thorough manner, and exceptional care was taken, by duplication of apparatus throughout, to obviate risk of breakdown. In operation the system has given most satisfactory results, and, as will be seen from figures presented in this paper the conversion has been justified by the increase in the capacity of the line, by reason of the improved speed and frequent service possible with multiple unit train operation, and that the economic results are striking.

West Jersey & Seashore Railroad. — This is the longer of two lines controlled by the Pennsylvania Railroad Company between Philadelphia and the seashore at Atlantic City, New Jersey, having a length of 65 miles as against 60 miles for the other steam operated line. For the first 30 miles out of Camden (near Philadelphia) the road serves a suburban territory, but on the remaining portion of the line to Atlantic City there is little local business. The main object sought in the conversion on this line was to furnish a test of the traffic-fostering and economic possibilities of electric traction as applied to main line express and local work.

The system employed is similar to that on the Long Island Railroad, namely, the A. C.-D. C. A third rail working conductor is used except for a short distance in the City of Camden and on one of the branch lines where it was thought best to install temporarily the overhead trolley. Power is generated in a single power house near the Camden end of the line and transmitted as three-phase current at 33,000 volts on an overhead pole line; the length of this line is about 75 miles. The circuits are in duplicate on a single pole line and notwithstanding that it is of a much higher voltage than before attempted for long distance railway service, it has been found entirely reliable.

Trains are composed entirely of motor cars each equipped with two motors of 200 horse-power each on one truck. Maximum trains of eight cars are hauled in express service, the maximum speed being 60 miles per hour and the average express speed with distance of 22 miles between stops 45 miles per hour.

The system, which is a simplification in many respects of the methods adopted on the Long Island, has operated very satisfactorily.

New York Central & Hudson River Railroad. — In 1903 legislation was passed by New York State compelling this company to supersede steam locomotives for service in their New York City tunnel entrance. The presence of smoke and steam in this tunnel had resulted in accidents, and the atmospheric conditions were such that the train speeds were restricted and the

capacity of the line cut down. This tunnel is also used by the New York, New Haven & Hartford Railroad Company for their entrance to the City.

Simultaneously with the decision to adopt electricity for traction in the tunnel, the Company decided to entirely remodel their extensive terminal in New York City and greatly increase its convenience and capacity, and it was further determined to carry out a comprehesive scheme of electric traction to the extent of a suburban zone of about thirty miles on the Hudson River and Harlem Divisions. At the present time reconstruction of the terminal is not complete and electric traction is conducted over a portion only of the lines mentioned.

The traffic consists of both through main line and suburban trains; the former are handled by electric locomotives (see figs. 2, 3 and diagram 4 [fig. 17]), and the latter by multiple unit trains. There are at present 47 electric locomotives, 125 steel motor cars and 55 steel trailers in use.

The electric system is the "A. C.-D. C." and has been made exceptionally complete throughout, much stress having been laid on the duplication of the various features and the use of storage batteries to give the maximum freedom from interruption to service. Two power houses are used, each of 20,000 kilowatts present capacity. Transmission is by means of duplicate 11,000 volt three-phase feeder lines, partly overhead and partly underground. There are eight substations, equipped with the usual transformers and rotary converter apparatus to furnish direct current at 650 volts to the working conductors. Each substation is provided with a storage battery varying in capacity from 450 to 900 amperes for eight hours. The working conductors are of the third rail under-running type, and sectionalizing and automatic switching features are very complete.

The system is the first example of electrification of a main terminus of a large trunk line railway system.

New York, New Haven & Hartford Railroad. — This company has done probably more pioneer work in electric traction than any other in the United States. In 1894, a small excursion branch to Nantasket Beach, near Boston, Massachusetts, was electrified for the overhead trolley system. Other installations were undertaken on short branch lines in 1895, 1897 and 1898. These installations may, however, be considered entirely experimental, and in some cases, they have been abandoned.

The conditions imposed by its entrance over the New York Central Company's tracks into the New York City terminal obliged the New Haven Company to arrange as well for electric haulage into this terminal. It was decided, however, to adopt a radically different electric system (the single phase) than that used on the New York Central, and to equip their main four-track line for operation to Stamford, Connecticut, a distance of 21·5 miles from the junction with New York Central tracks in New York.

The decision to use the single phase system of traction obliged the New Haven Company to equip their electric locomotives so that they could be operated on the New York Central Company's direct current system as well as on their own single phase system; this novel problem was worked out successfully by using a type of motor which operates on either system, and by providing the locomotive with a duplicate current control apparatus and contact devices for the overhead and third rail conductors.

The working conductor system on the New Haven is the overhead catenary, suspended from steel bridges set 300 feet apart, and the construction is elaborate and costly.

Power is obtained from a power house located near Stamford, and having an installed

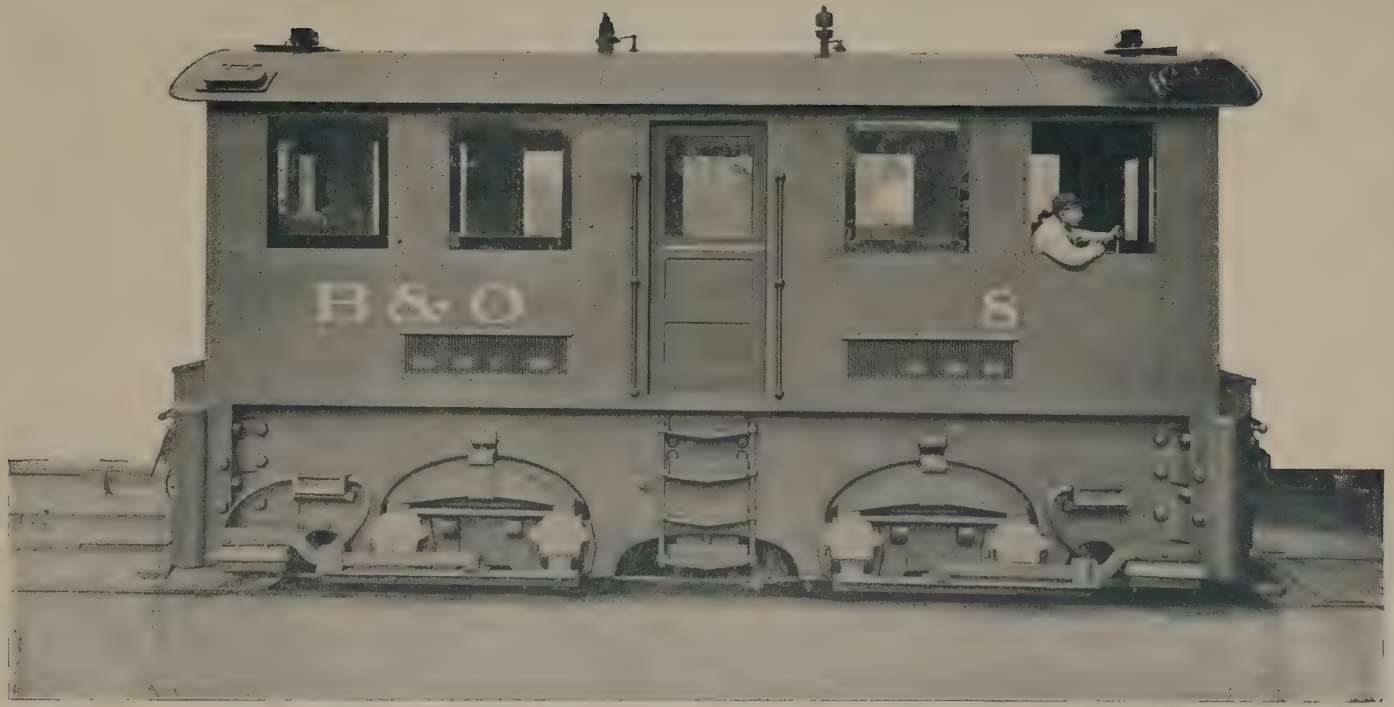

Fig. 1. — Baltimore & Ohio Railroad. Baltimore tunnel freight locomotive. (See diagram No. 2.)

Fig. 2. — New York Central & Hudson River Railroad. Latest type high speed passenger locomotive for New York Terminal service. (See diagram No. 4.)

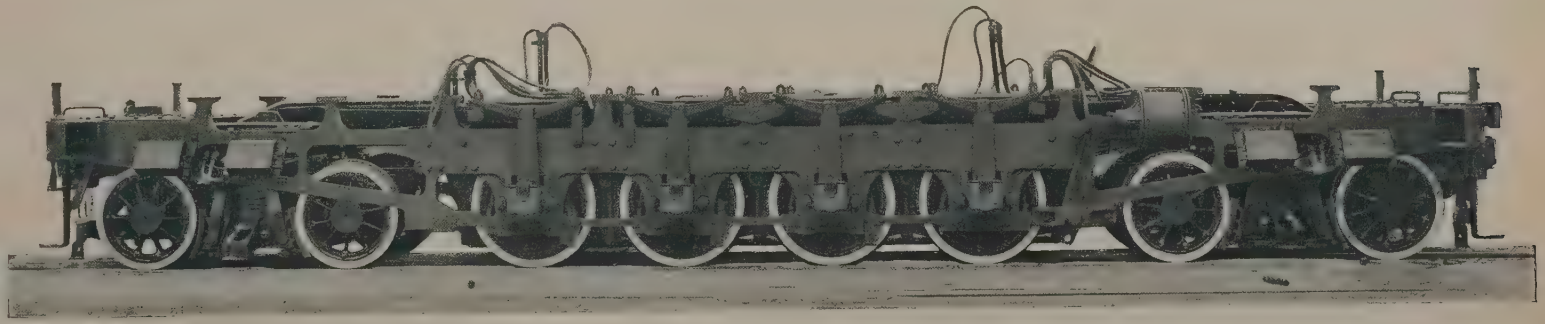

Fig. 3. — New York Central & Hudson River Railroad. Frame and running gear for passenger locomotive. (See diagram No. 4, and fig. 2.)

Fig. 4. — Pennsylvania Railroad. Experimental articulated truck type low speed passenger and freight locomotive. (See diagram No 5.)

Fig. 5. — Pennsylvania Railroad. Experimental A. C. high speed passenger locomotive. (See diagram No. 6.)

Fig. 6. — Pennsylvania Railroad double articulated electric locomotive for New York tunnel service. (See figure 7 and diagram No. 7.)

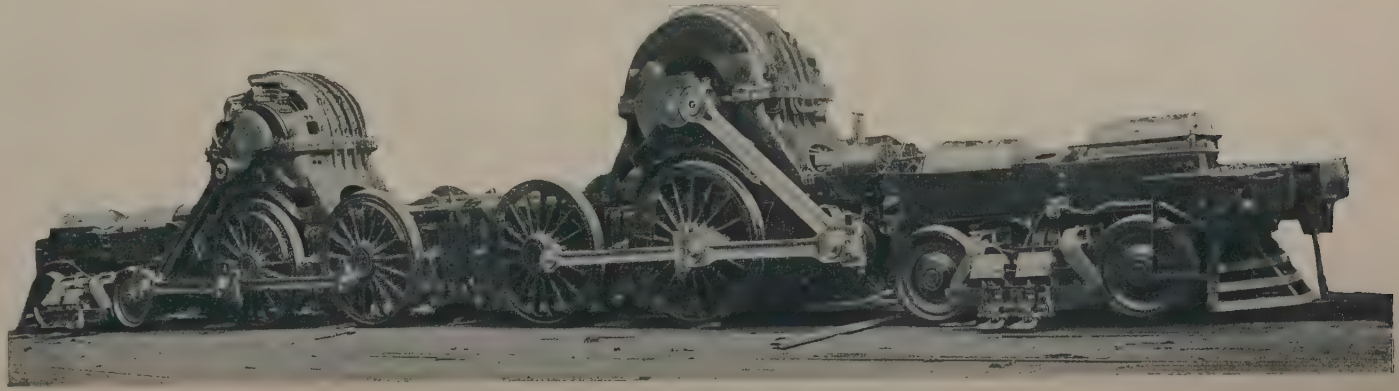

Fig. 7. — Pennsylvania Railroad double articulated electric locomotive for New York tunnel service : View of under-frame, motors and driving mechanism.

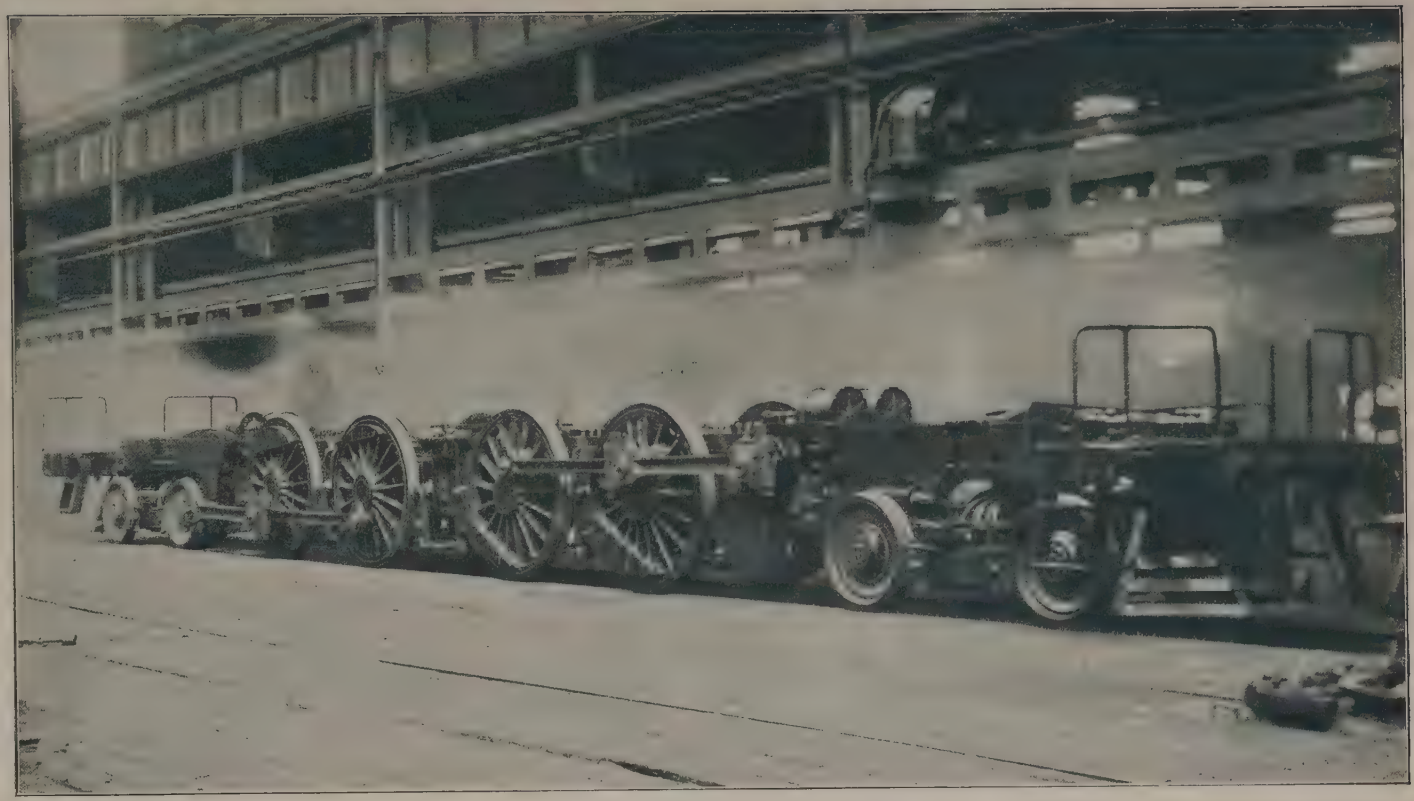

Fig. 8. — Pennsylvania Railroad. Underframe and running gear of articulated type passenger locomotive. (See figure 6 and diagram No. 7.)

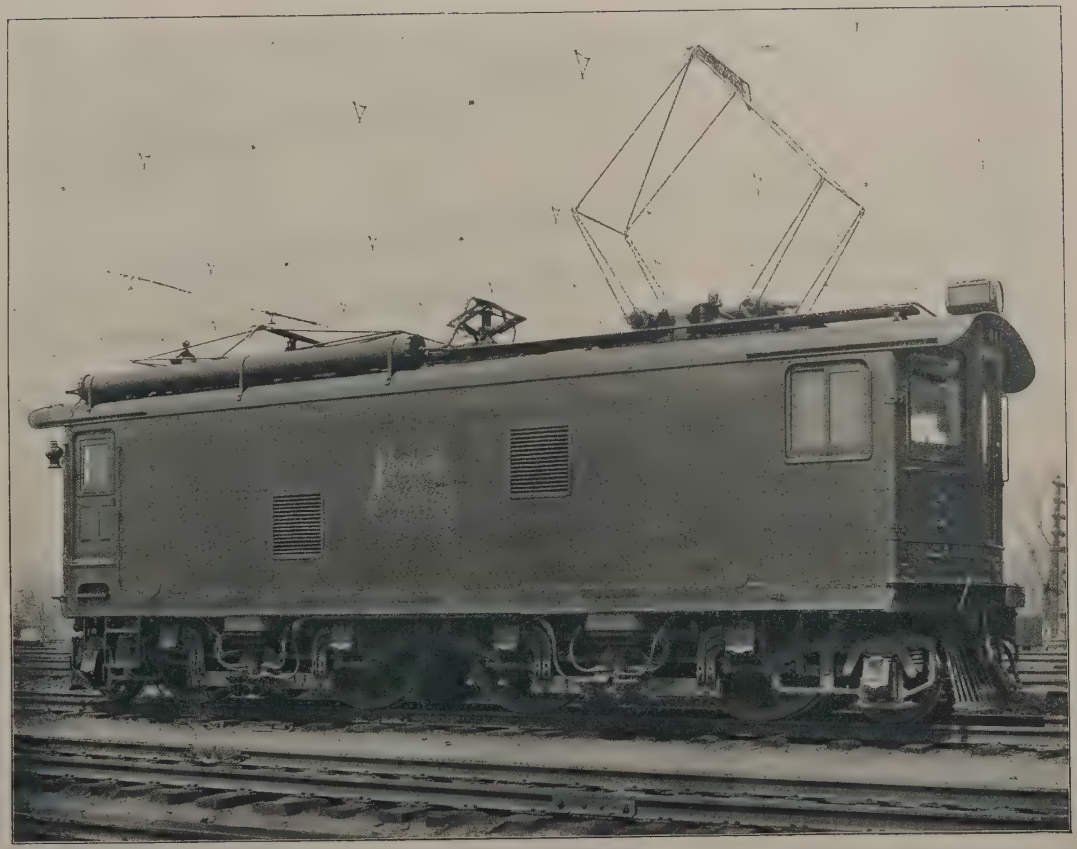

Fig. 9. — New York, New Haven & Hartford Railroad. Latest type 6-wheel bogie truck A. C. locomotive for New York terminal service. (See diagram No. 9.)

Fig. 10. – Grand Trunk Railroad. A. C. passenger and freight locomotive for St. Clair tunnel service. (See diagram No. 12.)

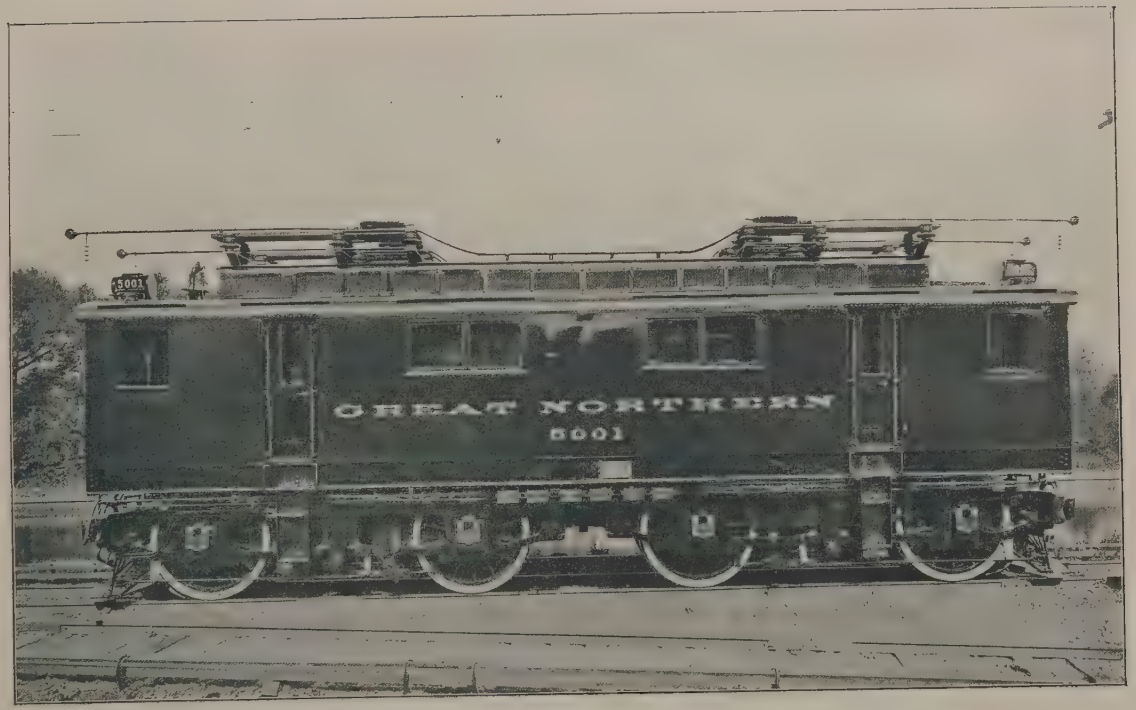

Fig. 11. — Great Northern Railway. Three-phase articulated truck locomotive for Cascade tunnel service. (See diagram No. 13.)

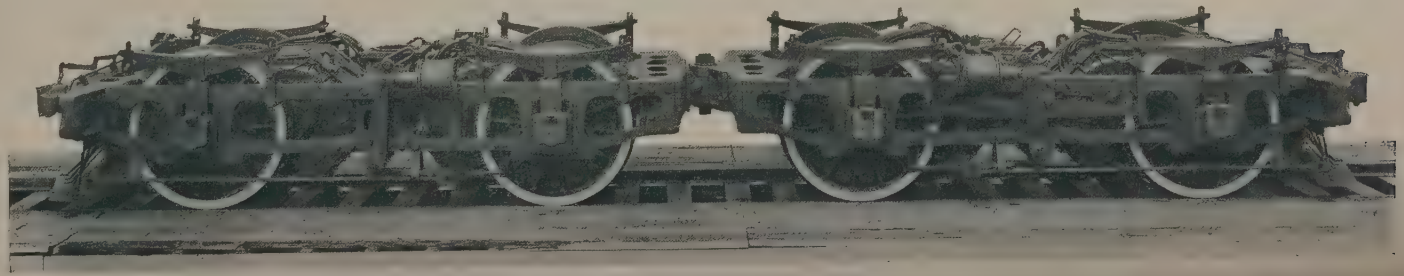

Fig. 12. — Great Northern Railway. Articulated truck arrangement for Cascade tunnel locomotive. (See diagram No. 13, and figure 11.)

Fig. 13. — New York Central Lines. Direct current articulated truck type locomotive for Detroit River tunnel. (See diagram No. 14.)

capacity of 15,500 kilowatts. Electric power is generated at 11,000 volts three-phase and transmitted to the working conductors as 11,000 volt single phase, and the voltage reduced on the locomotive by step-down transformers. No substations are used, but the working conductors are sectionalized at numerous points with automatic circuit breakers placed on bridges.

There are three important classes of service on this road; express, express local, and local. The express trains make the entire distance of 33 miles without stop; express local trains stop at an average of 8 miles apart; local trains have stops about two and two-tenth miles apart. All passenger service is conducted by electric locomotives (see figs. 9 and 22) although experiments are shortly to be made with the use of multiple unit trains for the local service.

Grand Trunk Railway. — This is an example of special electrification of a heavy grade subaqueous tunnel line for heavy freight and passenger service. The location is in a tunnel under the Detroit river, between Sarnia, Ontario, and Port Huron, Michigan. The tunnel length is 1·1 miles with a grade of 2 per cent in either direction from the center. It is a link in the main line of the Grand Trunk Railway, and its operation by steam locomotives was attended with risk because of the gases from same. The system adopted was the "Single-phase" employing a line potential of 3,300 volts. Trains are hauled by electric locomotives (see figs. 10 and 25), the steam locomotive being cut off before entering the tunnel. At present five single electric locomotives are in use, each weighing about 66 tons and equipped with three 225 horse-power single phase motors. Power is supplied from a single power house equipped with two 1,250 kilowatts steam turbo-generators supplying current at 3,300 volts, 25 cycles, three-phase, transmitted as single phase and reduced by transformers on the locomotives.

This installation has been in use a few months only but it is understood to be giving good satisfaction.

Spokane & Inland Railway. — This is an example of a new railway system of a character used mainly for freight haulage in the thinly settled part of the west; while it is not an example of the conversion of an existing steam road yet it shows the adaptation of electric traction to the character of service generally conducted by steam.

The road is an undulating one, containing many heavy and long grades, one being of 2 per cent and 8 miles long; only a small portion of the entire line of 135 miles is level. Freight service is hauled by electric locomotives, and passenger service by single motor cars, hauling at times a trailer. Two types of locomotives are used (see figs. 23 and 24), and forced ventilation is employed to increase the motor capacity on the locomotives. The average trailing load behind the locomotive is 350 tons.

Power is in part purchased and in part generated at power stations owned by the company. The purchased power is delivered at a frequency changing station containing four 1,000 kilowatts induction motor generators. The transmission voltage is 45,000. There are ten substations at various points on the road containing transformers which reduce the potential from 45,000 to 6,600 volts. The transmission system is of the single catenary type with a trolley wire carried on bracket arms from wooden side poles.

No reliable information has been obtained as to the practical operating results and economy of this installation.

Great Northern Railway. — An example of mountain-grade tunnel electric operation for freight and passenger trains, and having for its purpose the elimination of smoke from steam

locomotives in a long tunnel. The length of line is about 4 miles of which 2·6 miles is in a single track tunnel having a continuous grade of 1·7 per cent in the tunnel and 2·2 per cent in the yard approach. As the tunnel is not a division terminal, trains, including the road steam locomotives, are hauled up the grade by electric locomotives.

The electric system is the "three-phase," and is the first example of this system in America. A modified type of suspension is employed for the two overhead trolley wires required by this system. Power is generated in a hydro-electric plant situated about 30 miles from the tunnel, by two 2,500 kilowatts three-phase generators, and transmitted by two three-phase circuits at 33,000 volts. At a substation near the tunnel the potential is reduced to 6,000 volts and fed into the trolley wires, from which it is again reduced by transformers on the locomotive to 500 volts, three-phase for use in the motors. The locomotives (see figs. 11, 12 and 26), have a weight of 230,000 lb., all on drivers, and three locomotives combined will haul a maximum train of 2,200 tons of freight cars, or an equivalent train of 1,550 tons made up of cars and one Mallet compound steam locomotive. Speed of haulage is about 15 miles per hour.

As this installation has only recently (August, 1909) been placed in operation, no figures are yet available regarding its operation.

Pennsylvania Railroad. — The extensive electric traction system of this company for haulage of passenger traffic into its new New York City terminal is expected to be in operation in the summer of 1910. It is an example of the heaviest character of trunk line terminal operation, similar to that of the New York Central Company.

Physically, the line consists of 16.5 miles of tunnel, with a length of locomotive run of 8·6 miles on the western side into the terminal and a run of 12·0 miles on the eastern through the tunnels and over the Long Island Railroad. The tunnels are in part subaqueous and in part under the city of New York, and have long grades from the low points under the rivers of 1·5 per cent ruling to 2 per cent maximum.

Through trains will be hauled by electric locomotives, of which twenty four have been initially purchased, and locals from the Long Island side by multiple unit motor cars. The locomotives are shown in figures 6, 7, 8 and 20 and are permanently connected double units, each half equipped with a single direct current motor of 2,000 horse-power maximum capacity. One double unit will haul a trailing load of 550 tons at 60 miles per hour on a level track and will start and accelerate this load on the 2 per cent tunnel grade.

The electric system is the A. C.-D. C. similar in all essential respects to that of the Long Island Railroad installation and interconnected therewith. Power is generated at the central station referred to in the case of the above-mentioned road, transmitted to substations through cables in special duct lines incorporated into the tunnel structure, and fed into a special composition and section third rail weighing 150 pounds per yard. As in the case of the New York Central, the electric system throughout is designed to handle the very heaviest and most congested character of trunk line terminal service; in this case the requirements are practically those of a six track railroad handling at times trains in and out of a terminal on a minimum headway of two minutes on each track.

Southern Pacific Railway. — Referred to chiefly as a case of suburban line electrification of a steam railway with a relatively high tension direct current (1,200 volts) overhead trolley system for which important economies in construction and operation costs are claimed. The high tension current, practically double that used on the working conductors of other direct current systems,

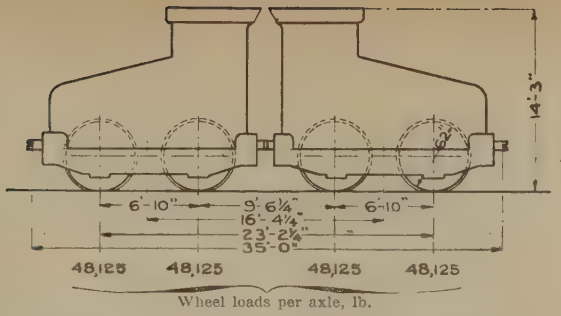

Fig. 14. — Diagram No. 1. Baltimore & Ohio Railroad. Passenger D. C. locomotive.

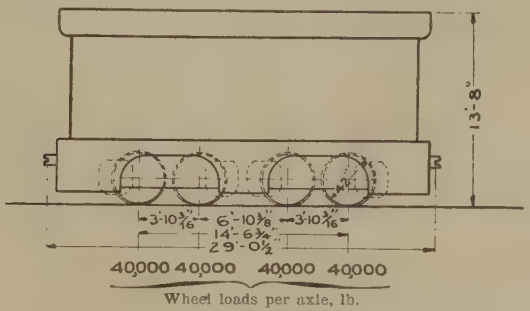

Fig. 15. — Diagram No. 2. Baltimore & Ohio Railroad. Freight D. C. locomotive.

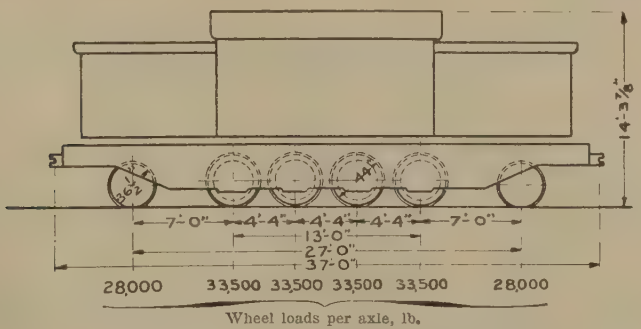

Fig. 16. — Diagram No. 3. New York Central & Hudson River Railroad. Passenger D. C. locomotive. Original type.

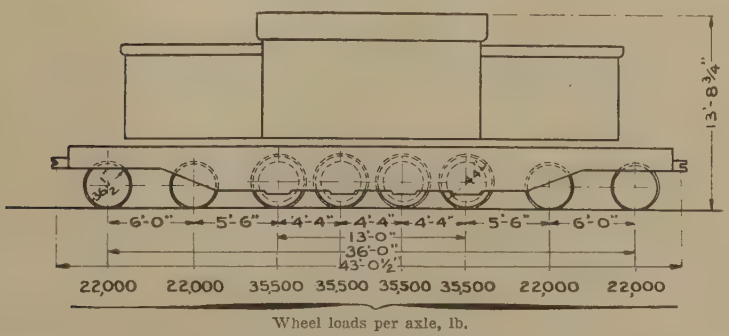

Fig. 17. — Diagram No. 4. New York Central & Hudson River Railroad. Passenger D. C. locomotive. Revised type.

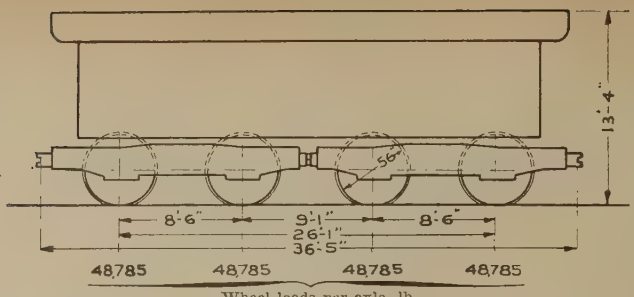

Fig. 18. — Diagram No. 5. Pennsylvania Railroad. Experimental D. C. locomotive.

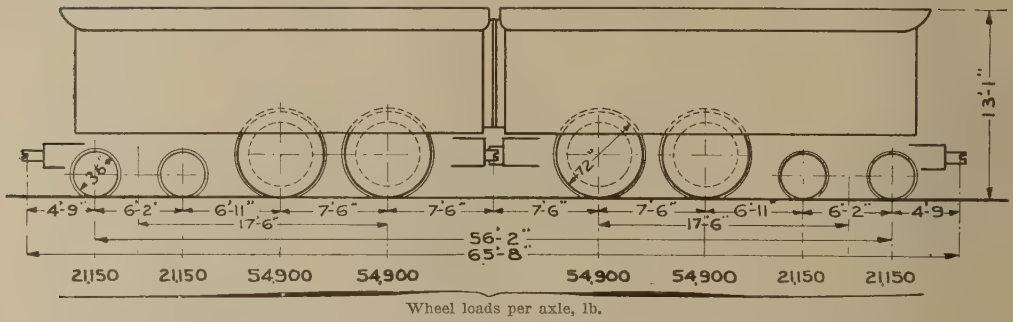

Fig. 19. — Diagram No. 6. Pennsylvania Railroad. Single phase A. C. experimental locomotive.

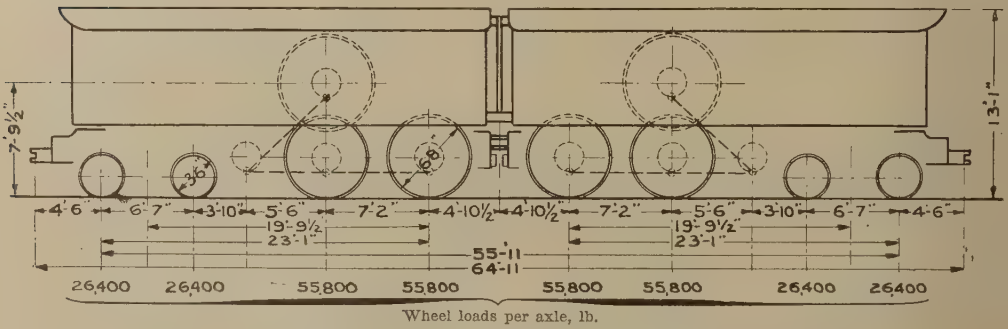

Fig. 20. — Diagram No. 7. Pennsylvania Railroad. D. C. articulated locomotive.
New York terminal passenger service.

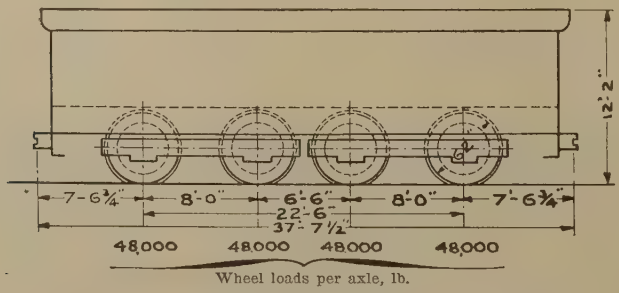

Fig. 21. — Diagram No. 8. New York, New Haven & Hartford Railroad. Passenger A. C. — D. C. locomotive.
Original type. Double bogie type.

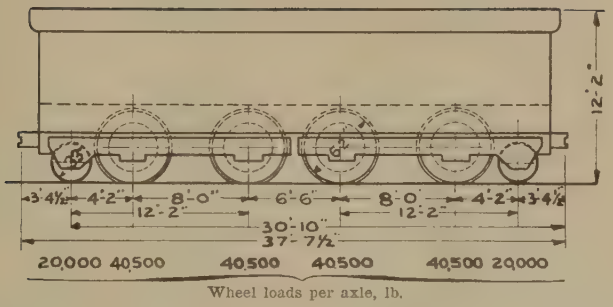

Fig. 22. — Diagram No. 9. New York, New Haven & Hartford Railroad.
Passenger A. C. — D. C. locomotive. Revised type. Double 6 wheel bogie type.

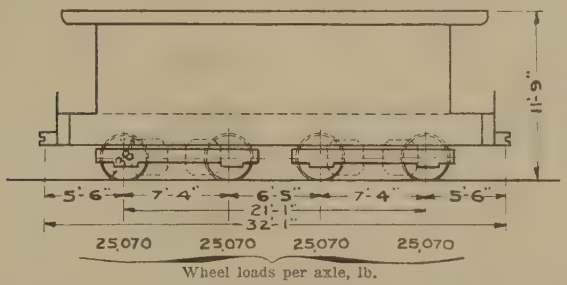

Fig. 23. — Diagram No. 10. Spokane & Inland Empire Railroad. Freight A. C. — D. C. locomotive.

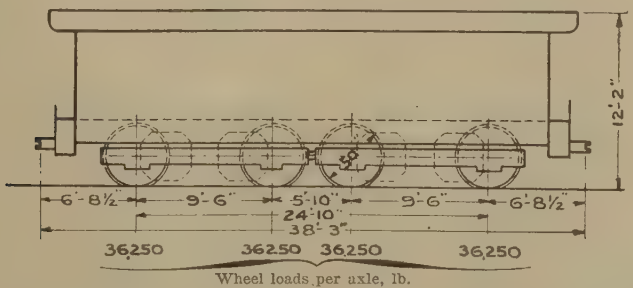

Fig. 24. — Diagram No. 11. Spokane & Inland Empire Railroad. Passenger A. C. — D. C. locomotive.

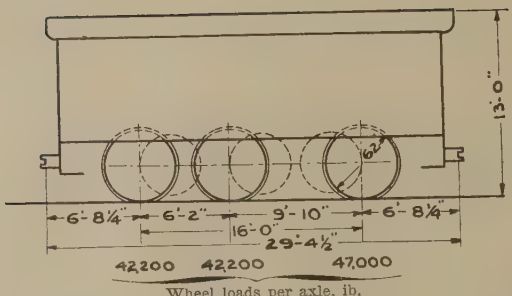

Fig. 25. — Diagram No. 12. Grand Trunk Railroad. St. Clair tunnel. Passenger and freight A. C. single phase locomotive.

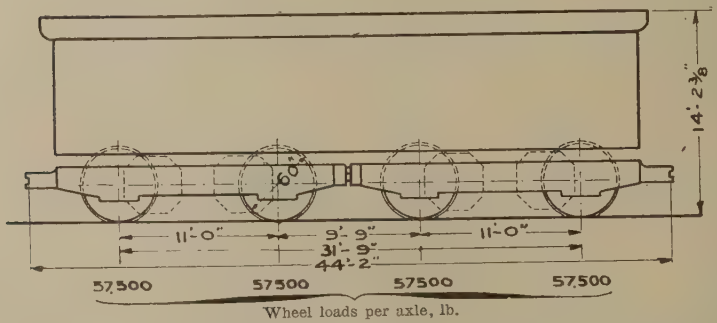

Fig. 26. — Diagram No. 13. Great Northern Railroad. Freight A. C. locomotive.

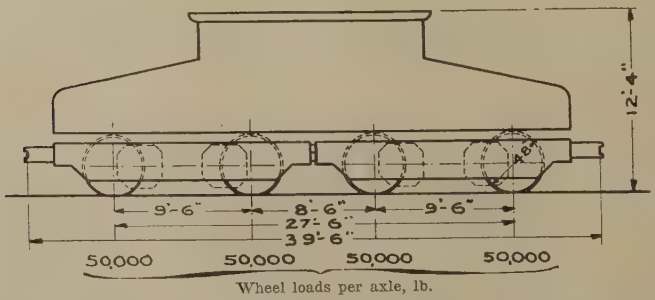

Fig. 27. — Diagram No. 14. New York Central Lines. Detroit River tunnels. Passenger and freight D. C. locomotive.

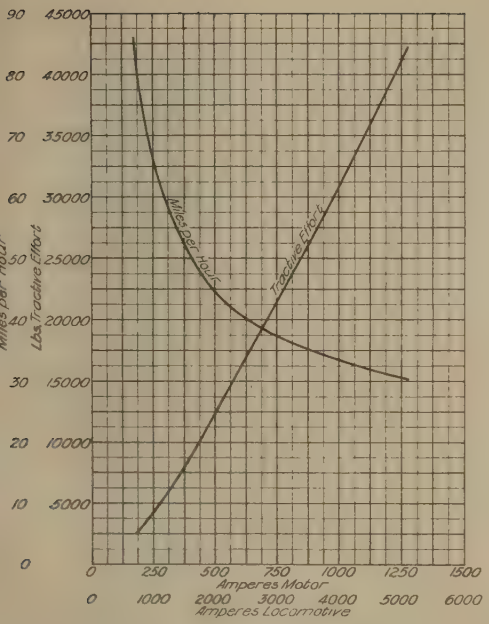

Fig. 28. — New York Central & Hudson River Railroad locomotive. Characteristic curve. Equipped with four G E 84-A motors. Curve No. 3 or 4.

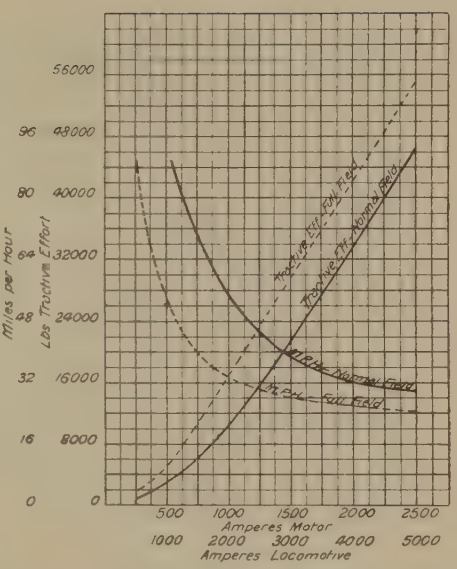

Fig. 29. — Pennsylvania Railroad locomotive. Characteristic curve. Equipped with two No. 315 motors. Curve No. 7.

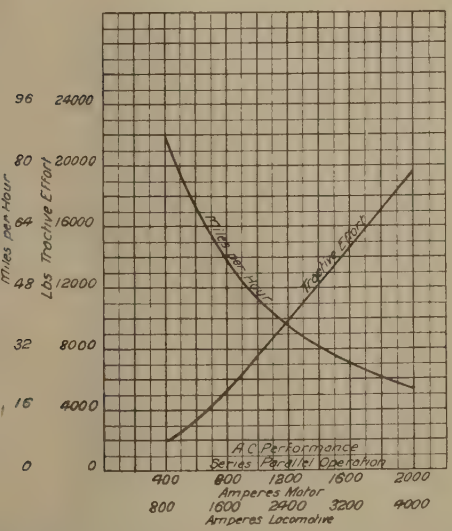

Fig. 30. — New York, New Haven & Hartford Railroad locomotive. Characteristic curve. Equipped with four No. 130 motors. Curve No. 8 or 9.

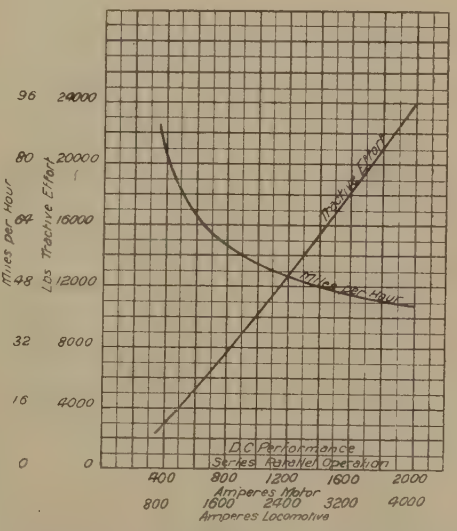

Fig. 31. — New York, New Haven & Hartford Railroad locomotive. Characteristic curve. Equipped with four No. 130 motors. Curve No. 8A or 9A.

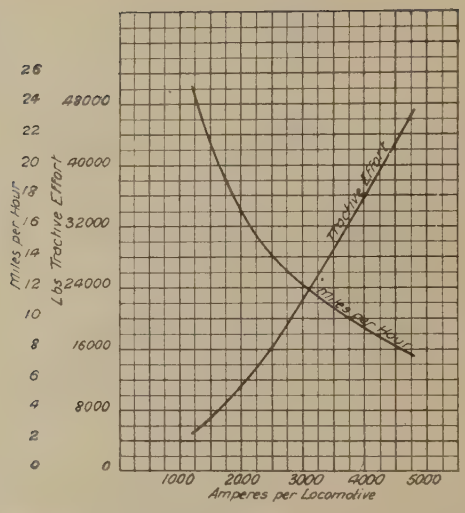

Fig. 32. — Grand Trunk Railway locomotive. Characteristic curve. Equipped with three No. 137 motors. Curve No. 12.

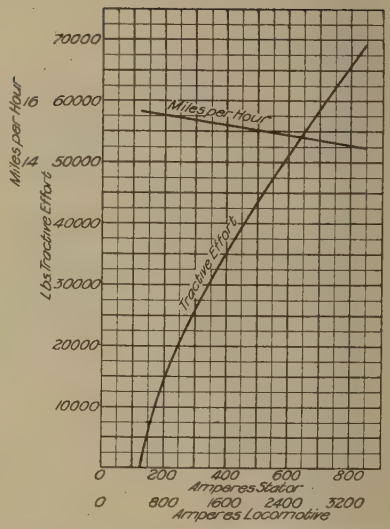

Fig. 33. — Great Northern Railway locomotive. Characteristic curve. Equipped with four G E I 506-A motors. Curve No. 13.

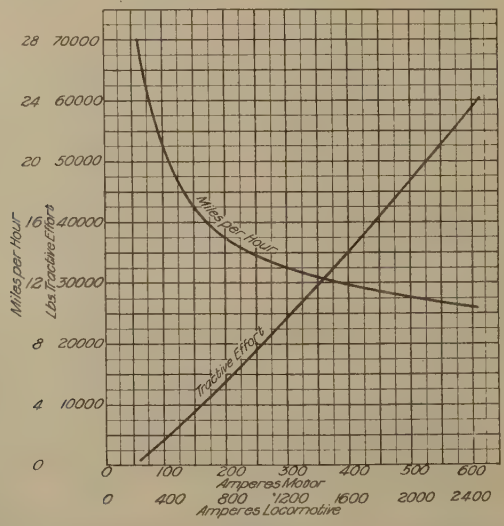

Fig. 34. — Detroit River tunnel locomotive. Characteristic curve. Equipped with four G E 209-A motors. Curve No. 14.

requires less feeder cooper and fewer substations for similar traffic conditions than with the 600 volt system and thus makes the first cost and operating cost of substations lower than for the latter.

The system has been in use but a short time and no particulars of operation are obtainable ; it will be interesting to observe whether sparkless collection of the very considerable quantity of current required at 1,200 volts for operation of heavy, high speed, multiple unit trains, will be possible.

APPENDIX B.

American railway association standard for location of third rail working conductors.

The following resolutions were adopted by the Association in accordance with recommendations of their Committee, in a report submitted 23 March 1908 :

Whereas, there is a constantly increasing number of roads being equipped electrically, which roads, in the natural course of business, interchange rolling stock with other lines not so equipped, and,

Whereas, unless lines of clearances for both rolling stock and maintenance of way structures are established, so that such interchange can be effected without interference, great inconvenience and expense will inevitably follow; therefore :

1° *Resolved*, That the diagrams showing lines of clearance as presented in the report be approved and made the standard of the American Railway Association; and that in the future construction of rolling stock and roadways, these clearance lines be carefully adhered to by the members of the Association;

2° *Resolved*, That in designs of new rolling equipment which is to be used in interchange, the clearance line K′, A′, B′, C′, including such horizontal and vertical variations which may in any reasonable probability occur in combination at one time, should not be exceeded. In determining this, the position of the equipment on a 20° curve should be considered, making allowance for the side-throw of the bolster and the consequent effect on the location of such portions of the equipment that are attached to the car body. Variations in equipment should be allowed for as follows : Horizontal, 2 1/2 inches in all; vertical, 4 inches in all;

3° *Resolved*, That in designs of new bridges, trestles, tunnels and platforms, no part that is continuous for more than seven feet should come within the space indicated for third rail structures, *i. e.*, A, B, C, D, E, F, G, H, I, J, K, and should preferably clear this line by at least one inch, as is shown by the line C″, D″, E″, F″, G″, but that structures which are not continuous for more than seven feet may be allowed to come to the line X Y.

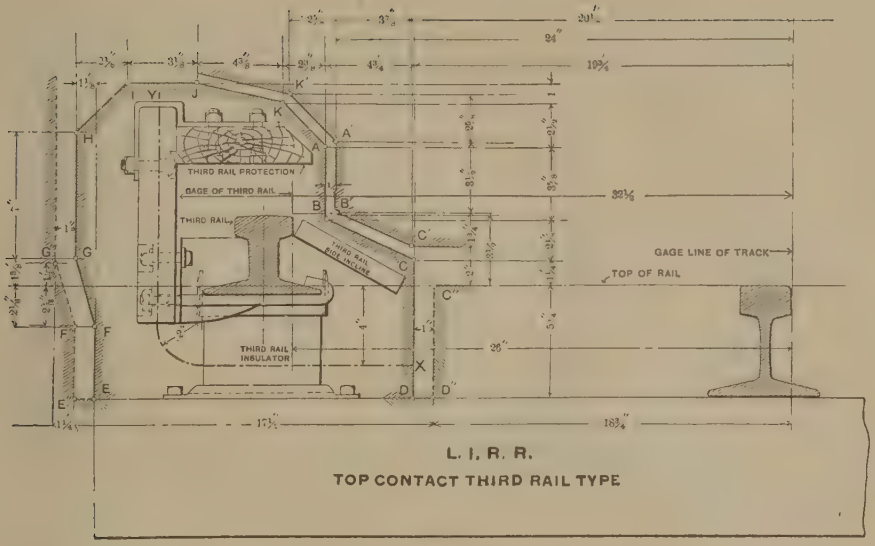
THIRD RAIL PROTECTION
GAGE OF THIRD RAIL
THIRD RAIL
THIRD RAIL SIDE INCLINE
THIRD RAIL INSULATOR
GAGE LINE OF TRACK
TOP OF RAIL
L. I. R. R.
TOP CONTACT THIRD RAIL TYPE

Fig. 35.

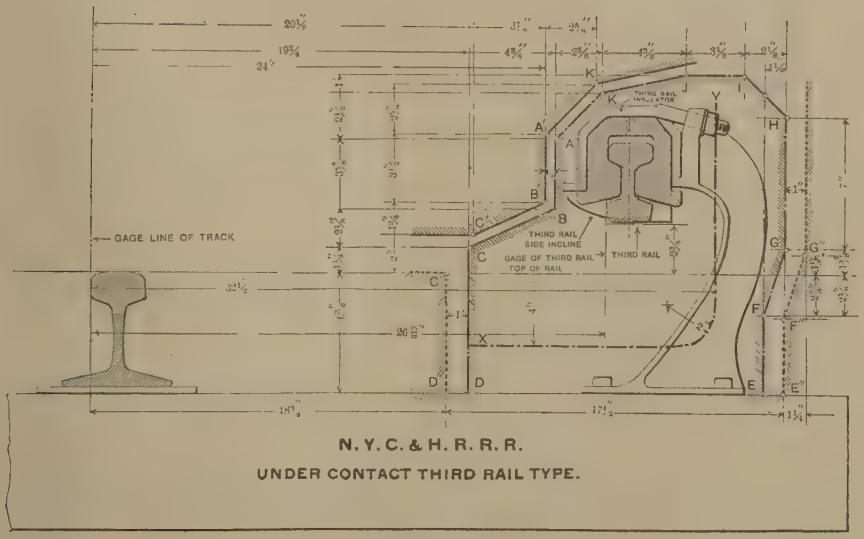
GAGE LINE OF TRACK
THIRD RAIL INSULATOR
THIRD RAIL SIDE INCLINE
GAGE OF THIRD RAIL
TOP OF RAIL
THIRD RAIL
N. Y. C. & H. R. R. R.
UNDER CONTACT THIRD RAIL TYPE.

Fig. 36.

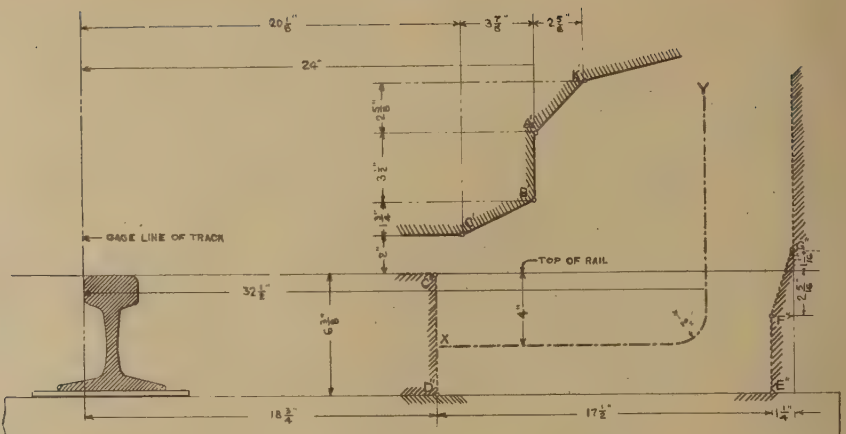
GAGE LINE OF TRACK
TOP OF RAIL
LIMITING PERMANENT WAY AND ROLLING EQUIPMENT
CLEARANCES TO PERMIT OF STANDARD THIRD RAIL LOCATION.

Fig. 37. — New York Central & Hudson River Railroad under contact third rail type.

Horizontal variations in rolling equipment should be allowed as follows :

Wear of axle, collars and boxes.	9/16 inch.
End play of brasses.	1/8 —
End wear on brasses	1/4 —
Wear on wheel flange.	3/8 —
Clearance between new flange and rail.	3/16 —
Constructional variations	1 —
Total. . .	2 1/2 inches.

(1) *Vertical variations in rolling equipment should be allowed as follows :*

	Passenger.	Freight.
Wear of journals and brasses	3/4 inch.	3/4 inch.
Radial wear on wheels. (Passenger, steel tires; freight, cast iron tires)	1 1/4 inches.	1/4 —
Compression of springs	4 1/4 —	1 3/8 inches.
Sagging at center of car	1 inch.	1 inch.
Constructional variations	1 —	1 —
Total. . .	8 1/4 inches.	4 3/8 inches.

(1) The probability that the combination of variations mentioned would occur in any one piece of equipment at the same time is very remote, and it seems not unreasonable to consider that when a vertical variation of more than 4 1/2 inches occurs it may be considered in the same light as a wreck with the consequent indeterminate damage done, although in this case it probably would be no worse than the breaking of the steps or some of the third rail protection.

[·621 .33] .

REPORT N° 1 [1]

(Germany)

By Dr. GLEICHMAN,

STATE COUNCILLOR OF THE BAVARIAN BOARD OF WORKS,
MEMBER OF THE PERMANENT COMMISSION OF THE CONGRESS, MUNICH.

I

Preliminary work for the introduction of electric operation on the German main railways.

Of the administrations of the German State railways, the Prussian-Hessian, the Baden and the Bavarian have paid special attention to the question, whether, and under what conditions, electric operation may profitably replace steam operation on main railways.

1. The *administration of the Prussian State Railway* has also carried out experimental trials of such operation, which have materially contributed to the elucidation of this difficult question. The first trial of such operation was carried out on the Berlin-Zehlendorf section of the Wannsee line from 1 August 1900 to 1 July 1902. Continuous-current at 650 volts was used, and the current was supplied through a third rail [2]. After these trials electric operation was introduced on the suburban line Berlin-Grosslichterfelde-Ost in July 1903, the same

[1] According to the state of knowledge up te August 1909.

[2] See *Zeitschrift des Vereins deutscher Ingenieure*, 1900, part 36; *Glasers Annalen für Gewerbe und Bauwesen*, vol. 47, No. 563; *Organ für die Fortschritte des Eisenbahnwesens*, supplement, 1900.

*

kind of current being used (1). When in 1903 the *Union Elektrizitäts-Gesellschaft* brought out a new alternating-current motor for use on railways, on the Winter-Eichberg system, the Prussian State Railway undertook to make a trial, on an experimental section, of this kind of current, which railway technicians thought very promising. This first alternating-current line was used for public traffic from July 1904 to October 1905; the year before experimental trains only were run (2). This experimental operation gave valuable information on the design of the conductors to be used with high tension, of the motors, of the controlling gear, of the collectors, etc. It was then decided, at the end of 1904, to introduce electric operation on this system for the busy traffic of the suburban line Olsdorf-Hamburg-Altona-Blankenese, because the system of using alternate current with an overhead conductor promised to require a simpler installation than the continuous-current system with third rail and rotary-current converted into continuous-current. This operation has now been at work since 1 October 1907. We must refrain from giving a description of the installation here. Detailed information about the construction and operation of this suburban line is to be found in a paper by C. Röthig in *Glasers Annalen* (3). Some figures about its operation will be given in another part of this report.

The administration of the Prussian State Railway is moreover making an extended trial of an alternating-current locomotive with a continuous output of 750 horse-power (three motors of 250 horse-power each, on the Winter-Eichberg systems) on the 1·75 kilometres (1·08 miles) long experimental line at Oranienburg. The experimental line, which in the first place serves for testing different systems of superstructure, also gives an opportunity for the continuous trial of the motors. The locomotive hauls a train-load of about 300 tons and runs every day, without driver, for periods of up to 20 hours without any interruption. At the same time several systems of overhead conductors are being tested.

Thus the administration of the Prussian State Railway has the merits of having carried out important preliminary work, in co-operation with the heads of the electrical industry in Germany, which was indispensable for later developments.

In the preamble to the railway-loan bill, which the administration of the Prussian-Hessian State Railway has submitted to the Prussian chamber of deputies (4), the merits of electric operation are set forth. Reference is made to the different cases of experimental working, to the suburban lines at Berlin and Hamburg-Altona, and after a short criticism on the kinds of current used, attention is drawn to the fact that the devices recently worked out make it possible to operate main

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(1) See *Glasers Annalen*, vol. 52, No. 622, and *Zeitschrift des Vereins deutscher Ingenieure*, 1903.

(2) See *Zeitschrift des Vereins deutscher Ingenieure*, 1904, part 9.

(3) Year 1908, vol. 63, Nos. 747 to 750; there is also a description by Mr. von Glinski in the *Zeitschrift des Vereins deutscher Ingenieure*, 1908, p. 1581.

(4) See *Deutscher Reichs- und Preussischer Staatsangeigen*, No. 75, of 29 March 1909.

railways electrically with safety and economy. The preamble states that it has become the undoubted duty of the administration to promote the introduction of electric traction with energy. In the loan bill means are asked for in order to bring about the introduction of electric traction on the Dessau-Bitterfeld section of the Magdeburg-Halle-Leipzig main line.

2. The *Baden State Railway* has expressed its opinion on the question of the electric operation of main railways in a memoir published in 1906 (1).

The Baden State Railway has not yet gone in for any experimental working.

In this memoir, the administration of the Baden State Railway proceeds to examine how electric operation can best be carried out on the Wiesental line, and gives comparative estimates, based on offers received from the *Allgemeine Elektrizitäts-Gesellschaft* and from the Siemens-Schuckert Works, for steam operation and electric operation. As motive power, the memoir takes continuous-current at 3,000 volts in the overhead conductor; the rotary-current generated at the central station is converted for the purpose at a substation (Siemens-Schuckert Works). A more general alternating-current project of the *Allgemeine Elektrizitäts-Gesellschaft* is compared with this.

As the electric energy is to be obtained from a Rhine power station at Augst-Wyhlen and the output is to be uniform throughout the year, the question is considered how this output can be divided between train traction, workshop operation and lighting, so as to obtain as complete an utilization as possible by electric storage.

3. The *administration of the Bavarian State Railway* has elaborated a memoir on the introduction of electric operation on the State lines; this was submitted to the Landtag by the Minister of Public Works on 7 April 1908.

In this memoir calculations are made to determine the amount of energy required to operate the main railways, and also that required for the whole Bavarian railway system. This amount is compared with the amount of water-power available.

A comparison is also made between the different kinds of current, and the question is examined, to what extent the different kinds of current are capable of meeting the requirements of main-railway operation.

Another section is devoted to the important and decisive question of the economy of the electric operation of railways; the separate items of expense in electric operation and in steam operation, which are affected by the electrification, are compared together.

Added to these general investigations, there are special investigations concerning individual lines. A very detailed comparison of the cost of the two methods of

(1) See *Der elektrische Betrieb auf der Wiesentalbahn;* Beilage zum Beiheft für den Nachtrag zum Eisenbahnbaubudget für 1906-1907; Carlsruhe, C. F. Müller.

operation is made for the Salzburg-Bad Reichenhall-Berchtesgaden line, on which electric operation is to be introduced shortly. The results of such calculations are also given for the lines Munich-Garmisch (with connexions), Munich-Holzkirchen-Bad Tölz-Schliersee, Holzkirchen-Rosenheim, and for the suburban line Munich-Gauting.

In the last section some water-power and electric installations are considered.

A summary of the chief results obtained is given in the concluding remarks. An appendix to the memoir considers the selection of the kind of current and the principles of the electrification of main-line railways. The appendix concludes with a comparison of the different kinds of current available, in the form of a table containing 44 items.

There is a supplement to the memoir of the Bavarian Board of Works in which a summary of all the economical and other determinations is given.

A comprehensive abstract of this Memoir and of the supplement was published by Engineer J. Jacqmin in the *Bulletin of the Railway Congress* for January 1910.

The table with the comparison of the different kinds of current is reproduced verbatim, with the exception of the notes and the calculations of the alternating-current and the continuous-current conductors, so that this memoir need not be further considered here. The reader is referred to the *Bulletin*. As only a limited number of copies of the memoir was issued, and the supplement was only issued to the parties concerned, Dr. Reichel, editor of the paper *Elektrische Kraftbetriebe und Bahnen*, at the instigation of the Board of Works, published the contents of the memoir in that paper (1908, Nos. 13 to 19), and also an account of the different methods of calculation and of graphical representation used in the investigations, as given in the supplement; so that the information is now available for a larger circle of readers. The administration of the Bavarian State Railway has not gone in for any experimental working.

The only line operated is a local line, 12·5 kilometres (7·8 miles) long, from Berchtesgaden to Schellenberg, where it joins the Austrian local line to Salzburg; this was opened in 1908. Continuous-current at 1,000 volts is supplied by a small water-power plant, with an output of 900 horse-power in summer and 450 horse-power in winter. In summer 1909 this line was connected with the local line, 4·3 kilometres (2·7 miles) long, to the Königssee. The traffic, which is chiefly passenger traffic, is worked by nine motor cars, each with 2 motors of 60 horse-power. Four cars are equipped with a simple system of control, so as to make it possible to run trains consisting of 2 motor cars and 3-4 trailers.

An instance of electric operation, which deserves special attention, is that operated on the local line Murnau-Oberammergau by the Munich-Lokalbahngesellschaft. This line is 23·6 kilometres (14·7 miles) long, and there are many up and down gradients (30 per mil); it was arranged by the former owners of the line, a south German local railway company, which was liquidated in 1900 for rotary-current with 50 cycles at 800 volts in the overhead conductor, and was altered in 1904 to suit

alternating-current with 16 cycles at 5,000 volts in the overhead conductor (1). The motor cars are each equipped with 2 motors, each of 100 horse-power; supplied by the Siemens-Schuckert Works. This alternating-current operation has supplied valuable information for the future development of this system of operation.

4. Besides these investigations and trial operations, for determining the suitability of continuous-current and alternating-current for main-railway operation, we must not omit to mention the memorable experimental runs of the *Studiengesellschaft für elektrische Schnellbahnen*; the administration of the Prussian State Railway, the Directorate of the Military Railway, and the electrical firms, Messrs. Siemens & Halske and the *Allgemeine Electrizitäts-Gesellschaft* all contributed to this success. The trial runs were made on the Military Railway in the months September-November 1903 (2). These high-speed trials were carried out with high-tension rotary-current. Their object, in the first place, was to determine how a high-speed line should be constructed, and to investigate the conditions under which such a service could be operated. It was less intended as a test of the merits of one kind of current for main-railway operation as indeed the lateral position of the overhead conductor and the collector projecting into the cross-section show. Besides at that time rotary-current was the only kind of current available. At the present day, in deciding the kind of current to be used, alternating current would compete in the case of high-speed lines also, although the conditions on a high-speed line, used only for passenger traffic, are materially different from those on ordinary main-railways.

No experiments have been made with rotary current on the German State Railways, in order to test its suitability for main-railway operation. But rotary-current has been tested thoroughly by Messrs. Siemens & Halske on a private experimental railway line in the years 1897 to 1900 (3).

II

Reasons for introducing electric operation. Results, and further plans.

1. The administration of the Prussian State Railway proceeded to introduce electric operation on the suburban lines Berlin-Grosslichterfelde-Ost and Ohlsdorf-Hamburg-Altona-Blankenese in order to give a more frequent service, to suit the size of

(1) See *Elektrische Kraftbetriebe und Bahnen*, 1905, parts 20 and 21.

(2) See the report of the Gesellschaft, also W. Reichel, *Verwendung des Drehstromes über den Betrieb elektrischer Bahnen*, R. Oldenburg, 1903, and *Elektrotechnische Zeitschrift*, 1901, Nos. 34 to 41, and 1902, No. 32.

(3) See *Elektrotechnische Zeitschrift*, 1900, No. 23.

the trains to the traffic and so reduce working expenses, and to shorten the time required for the journey (as compared with steam operation) by starting and stopping more quickly. In addition, the greater cleanliness was also taken into consideration, as no smoke would be produced in towns.

The service is now carried out regularly on both lines. On the Hamburg-Altona suburban line, considerable interruptions took place in the months April-July 1908. These were partly caused by the design of the armatures of the turbo-dynamos and of the transformer, partly by the absence of a second insulation of the overhead conductors. The motors on the cars showed no irregularities. After a short-circuit winding had been introduced into the armatures of the generators in order to damp the alternating field (1), and transformers of the core pattern instead of the shell pattern had been selected, and after the overhead conductors had been supplied with a second insulation, no further irregularities took place. The rolling stock consists of 61 double motor cars, each equipped with 3 motors of 110 horse-power each. This number does not suffice for the traffic, which has materially increased since electric traction was introduced. The capacity of the power station is also not sufficient. At present there are every day 362 electric trains, and between Blankenese and Ohlsdorf 58 steam trains. It will only be possible to operate the whole traffic electrically when 25 more double cars and another generator are available. The new cars will each have 2 motors, but of 180 horse-power each. This makes them cheaper, lighter and more efficient.

The administration of the Prussian State Railway is in the first place going to extend electric operation to the main lines between Magdeburg, Halle and Leipzig, with the object of utilizing the neighbouring beds of cheap inferior lignite in an economic manner, by burning them on the spot. In this case, the calculation of the working expenses has shown an acceptable figure. The Dessau-Bitterfeld section, 25·6 kilometres (15·9 miles) long, is the first one which will be taken in hand.

2. The administration of the Baden State Railway, in electrifying the Wiesental line, has in view the utilization of a cheap water-power; it will depend on the results obtained on this line, whether electric operation will be extended to other lines also. At present no other projects are proposed.

The Wiesental line runs from Bâle to Schopfheim (23 kilometres [14·3 miles]) and there forms two branches, one to the south to Säckingen (7 kilometres [4·3 miles]) and one to the north to Zell (20 kilometres [12·4 miles]); the total length is accordingly 50 kilometres (31 miles). The power station is 8·9 kilometres (5·5 miles) east of Bâle. The current required will be supplied in the form of rotary-current from the Augst-Wyhlen station (Rhine) of the Rheinfelden Power Company; the amount to be paid for it is fixed at 120,000 marks (£6,000) per annum for 1,040 kilo-

(1) See Niethammer, *Zeitschrift des Vereins deutscher Ingenieure*, 1909, No. 26, p. 1018.

watts uniformly supplied; this current will be transformed at substations into current suitable for use on the railway.

At Baden in the Black Forest, large water-powers are obtainable for generating electricity at a cheap rate, so that there are favourable conditions available for the further extension of electric operation.

The electric operation of the Wiesental line is designed for an extensive passenger and goods traffic.

The working conditions there are certainly very suitable for thoroughly testing the suitability of electricity as motive power (see summary below). The installations for the electric operation are now being constructed (see under locomotives).

3. The administration of the Bavarian State Railway intends in the first place to electrify the line Salzburg-Bad Reichenhall-Berchtesgaden. The electric energy is to be obtained from a power station which is to be erected at Reichenhall. The effective head is 20 metres (65 ft. 7 in.); the minimum quantity of water is on the average 10 cubic metres (353 cubic feet) per second; by putting up a dam in the Saalach a reservoir having a capacity of 800,000 cubic metres per metre (8,611,439 cubic feet per foot) of fall of level can be obtained. The installation is designed for a maximum consumption of water of 40 cubic metres (1,413 cubic feet) per second. A conduit 560 metres (612 yards) long brings the water to the water lock. The capacity of the power station is such that the output not only suffices for the maximum loads on the railway, but also for lighting and power installations of different kinds. Consequently, in addition to the current used on the railway, there will also be generated rotary current with 50 cycles for particulars of the railway service (see summary below).

The construction of the power station will be begun at the end of 1909.

Then also there is a project to utilize the existing difference of level between the Walchensee and the Kochelsee (200 metres [656 feet]) and the storage capacity of the Walchensee by leading across the Isar (see the article "Weisse Kohle" in the *Zeitschrift für Wasserwirtschaft*, Munich, 1909, Nos. 22, 23, 24; the Walchensee competition) and so, to begin, operate the Munich-Garmisch and the Holzkirchen lines and their branches electrically. It is also proposed to use electric operation on the projected new lines Garmisch-Mittenwald-Scharnitz, with extension to Innsbruck, and Garmisch-Griesen with extension to Reutte to connect with the Pfronten-Kempten line. Negociations with the Austrian promoters are already in progress.

The administration of the Bavarian State Railway has in addition to the above also laid an embargo on a number of other water-powers. It considers the utilization of water-powers for the electric operation of railways, combined with the supply of electric power for other purposes, as an important task of great economic importance.

4. Now although in the opinion of the administration of the Prussian, the Baden and the Bavarian State Railways, a greater extension of electric operation would be

justifiable (for it can compete with steam operation both from the technical and the economic point of view) than is at present contemplated by them, in their present plans, yet the doubts of the military authorities still form a material obstacle to the further development of electric operation, even in those cases where the economic conditions are favourable. The operation on the sections mentioned is also to serve the purpose of enabling the military authorities to ascertain to what extent electric operation can satisfy military requirements. The results obtained on these lines will contribute to the elucidation of this question.

III

The kind of current suitable for main-railway operation.

When a railway administration proposes to introduce electric operation on a large scale on a connected railway system, it has in the first place to consider the important question, what kind of current to use. Leaving individual special cases out of consideration, it is not possible to select for every section of line that kind which calculation shows is the most economic in that case; but it is necessary, in the interests of uniform and economic operation, to settle on one general useful system, to be applied on all the lines.

The administrations of the German State railways could come to a decision on this point at a time when alternating current was available, and could also fully compete with the systems first used, namely the continuous-current system, which had also been improved so that higher voltages could be used, and the rotary-current system, which had been in use for long periods of time and had been developed in other countries to a high state of perfection.

We must refrain here from the enumeration of the separate properties of the different kinds of current and would refer our readers to the article which appeared in the *Bulletin* (1) where they will find reproduced the detailed comparison of the different kinds of current, which was given in the form of a table in the memoir of the Bavarian Board of Works.

The three German State railway administrations named have decided to use alternating current (single-phase) because, among the kinds of current available, the advantages of single-phase alternating current are considered to be much greater than its disadvantages.

This decision had as basis :

1° The simple and economic transmission of the energy from the power station

(1) See *Bulletin of the Railway Congress*, Nos. of November 1907, March, September and November 1908, January, February, March, August and December 1909.

to the overhead conductor without complicated intermediate appliances, as required in the rotary-current to continuous-current system;

2° The overhead conductor, which as a *single-pole* system can be arranged to suit the needs of the main-railway traffic for higher voltages, and is materially cheaper to construct and work and above all is safer than in the case of rotary-current. More especially is the arrangement at switches simpler;

3° The complete adaptability of the rotary-current motor to the needs of main-railway traffic : speed varying with the train load, greater tractive power when starting, and most independence of a voltage drop (see fig. 34 et 35).

These three points include at the same time the requirements which have always been considered necessary by the German State railway administrations in the case of electric operation.

The chief disadvantages of rotary-current working as follows :

1° Alternating-current requires a commutator like the continuous-current motor, while the rotary-current motor only requires collector rings (cascade or resistance connexions) or can also be constructed like the Simplon machine with armature short-circuit (changing of pole connexions);

2° The alternating-current motor must be constructed for low voltages, and hence requires a transformer to reduce the voltage from that in the conductor to that suitable for the motor. This transformer produces a loss, if only a slight one, and increases the weight of the car. This increase in weight necessitates the consumption of more energy.

Here it must be mentioned that the greater consumption of the alternating-current locomotive as compared with the continuous-current locomotive can be counterbalanced by the materially-lower cost of the conducting system (1).

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(1) In the Bavarian Memoir, an instance is given (see appendix p. 25 item 27, or *Elektrische Kraftbetriebe und Bahnen*, 1908, part 16, table V, item 27) showing that for equal distances of the feed points, the alternating-current voltage need only be 33·5 per cent higher than the rotary-current voltage, if there is to be the same loss in both cases. At the same time, the weight of copper in two rotary-current conductors, is twice as great as in the case of the alternating-current conductors; each wire being assumed to have a cross-section of 100 square millimetres (197,350 circular mils), so that it may have the necessary strength. The running rails are taken as weighing 43·5 kilograms per metre (87·7 lb. per yard). Now no hesitation need be felt in having a tension of 10,000 volts in the alternating-current conductors (the Swedish State Railway has even adopted 15,000 volts, and on the experimental Seebach-Wettingen line of the Swiss Federal Railway this voltage is at present being tried in actual practice), while in the case of the rotary-current conductor a tension of only 3,000 volts is assumed, partly on account of the insulation of the two wires, partly because this is a suitably-high voltage for the motor; otherwise a transformer would become necessary in the case of rotary-current also. Taking this ratio of the voltages into consideration, then, in the case of conductors composed as described, the feed-points being at equal distances and the same amount of energy being transmitted, the loss in the alternating-current conducting system is only 0·16 of that in the rotary-current system ($p_1 = 0{\cdot}16\ p_3$). Or for losses that are equal, the distance of the feed-points can be six times as great in the case of

3° As the twisting moment of the alternating-current motor is a sine square junction of the strength of current and magnetic field, with a maximum value, an alternating-current locomotive as many allege requires to have considerably greater adhesive weight than a continuous-current or a rotary-current locomotive, in order to keep the wheels from slipping.

This theoretical fact is of no importance in practice, as the inertia of the revolving masses compensates for the variations, the maximum values of which are limited to very short intervals of time, of the order of magnitude of a fraction of 0·033 second in the case of 15 cycles (1).

In addition to the important decision as to the kind of current to be used, there are *two important points* which have to be settled, namely the *frequency* and the *voltage in the conducting system.*

In the case of joint stations, entered by the electrically-operated lines of different administrations, and in the interests of a standard form of rolling stock, the determination of these two points is of the greatest importance.

As regards *frequency* there are two numbers to be considered; namely 15 and 25.

The three German administration which are definitely going to make installations, take 15 cycles as the average.

The Baden State Railway was the first to decide on this frequency for their Wiesental line.

In their memoir, the administration of the Bavarian State Railway had not yet decided about this important point; it only mentions several times that taking conductors and motors into consideration, it is advisable to keep this number low (10 to 16; not above 25). The experience since gained in the construction of motors has led to the elucidation of this question, and will induce the Bavarian administration to have 15 as the average frequency in their installations.

The administration of the Prussian State Railway is also going to use 15 cycles on the Magdeburg-Leipzig-Halle line (2).

The selection of 15 as the frequency has the following points its favour :

The frequency influences the dimensions of the generators and the transformers, so that these become lighter and consequently cheaper if the number of cycles is increased; it influences the conducting system in the way, that running loss and

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continuous current as in that of rotary-current system($l_1 = 6{\cdot}22\ l_3$). For the losses vary inversely as the square of the tension and the lengths of line vary directly as the square of the tension. If we assume that in order to cover transformer losses and the increased weight of the locomotive, 20 per cent more energy has to be transmitted, then other conditions being equal, the alternating-current loss is 20 per cent of the rotary-current loss ($p_1 = 0{\cdot}2\ p_3$); or, for equal losses, the distance of the feed-points is five times as great in the case of continuous-current as in that of rotary-current.

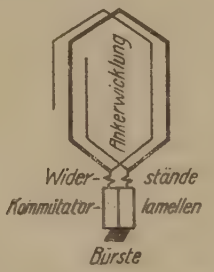
(1) See Ossanna, *Elektrische Kraftbetriebe und Bahnen*, 1906, part 13; Bavarian memoir, appendix, p. 19, note to item 3.

(2) See *Elektrische Kraftbetriebe und Bahnen*, 1909, part 1, Rundschau.

voltage drop is smaller, the smaller the number of cycles. Thus the conditions under which the energy is transmitted, in the case of fewer cycles, more nearly approach the case of continuous-current transmissions, which is the most efficient, because for a given output of watts a given voltage, the intensity of current, on which the transmission losses depend, is least. In the case of alternating current, the greater the number of cycles, the greater (for the same output and voltage) the intensity of current, and consequently also the greater the loss when there is a long transmission. In the case of main-railway operation, great distances are more especially in question if water-powers are to be utilized. It is therefore economic to keep the number of cycles low. The frequency also influences the driving machinery, if this consists of steam turbines, for the number of revolutions becomes less, the smaller (for an equal number of poles in the dynamo) the number of cycles. In the case of steam turbines a considerable, but not too great, number of revolutions is desirable.

The periodicity has a very great influence on the motors used on the track. This is the most important link in the whole chain. Its influence will therefore be paramount. There is one property which gives rise to particular difficulty in the construction of an alternating-current motor with commutator, which is absent in the case of continuous-current motors.

This we will consider shortly.



Explanation of German terms : Ankerwickelung = Armature windings. — Bürste = Brush. Kommutatorlamellen = Commutator segments. — Widerstände = Resistances.

The brushes always bridge at least two com mutator segments (see fig. above), so that the windings of the armature which are brought to these segments are at times short-circuited. The variable magnetic flux which is produced by the alternating current, produces in the short-circuited winding, as in the case of a transformer, a short-circuit voltage which becomes greater the stronger the magnetic field and the greater the number of the windings and the number of the cycles.

Now when the momentarily short-circuited armature winding is again opened by the movement of the motor, a current is produced corresponding to the voltage and the resistance of the short-circuited winding, which results in sparking, to the detriment of the commutator segments.

This phenomenon reduces the efficiency of the motor and above all the life of the commutator, if it becomes at all marked. Thus there is every reason for eliminating it as much as possible.

With this object in view resistances can be inserted between the commutator segments and the armature windings (*see figure*), so as to increase the resistance of the short-circuited armature winding and consequently in order to reduce the intensity of the current. But this is an unsatisfactory device in the case of a railway motor; the resistances become heated by the intensity of the short-circuit current, and this necessarily tends to head the motor also. Moreover they require room, which could be utilized better for devices increasing the efficiency of the motor.

The short-circuit voltage can also be opposed by auxiliary windings, producing the opposite effect as soon as the motor runs at a given number of revolutions. Thus they do not yet have any effect on starting, although it is just at this time that the short-circuit voltage is high, because a great tractive effort is required, and hence a great intensity of current and a strong magnetic field. But locomotives used for goods trains and shunting operations have to start very frequently, and it must be possible to do so repeatedly without injuring the motors.

The most effective means for eliminating short-circuit voltage is, besides having a small number of windings in the coil, above all to have as low a frequency as possible.

These relations apply above all to those classes of alternating-current motors, which are built similarly to continuous-current series-wound motors, and which have different auxiliary windings. Motors of this class are built, with but little modification, by most of the electrical firms [1].

Another class of motors is represented by the Eichberg series-wound motors, as manufactured by the *Allgemeine Elektrizitäts-Gesellschaft*. The Eichberg motor [2] is it is true also built, like the former class, more conveniently for a frequency of 15; but it is asserted that it can more easily be adapted to a higher frequency, and Eichberg selects 25. The object of this number is to make it easier to utilize power stations built for railway operation for other purposes also.

The power stations which will be built in order to operate railways electrically, will not only have the task of supplying the electric energy for hauling the trains, but will also fulfil important functions in general economics; for by combining together all possible applications the production of electric energy will be cheapened and it will be possible to supply current at a cheap rate to farms, smaller industries

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[1] *Elektrotechnische Zeitschrift*, 1909, part 7 : « Ueber den Anlauf von Wechselstrom-Kommutatormotoren für Einphasenstrom; 1906, parts 23 and 24: Wechselstrom-Reihenschlussmotoren der Siemens-Schuckert-Werke; 1907, part 34 : Mitteilung über den Wechselstrom-Reihen-Schluss-Motor der Siemens-Schuckert-Werke; 1908, parts 1, 2 and 3 : Ueber Wechselstrom-Kommutatormotoren mit besonderer Berücksichtigung der Bahnmotoren. (Doppelschluss-Motor der Felten & Guilleaume-Lahmeyer-Werke.)

[2] See *Elektrotechnische Zeitschrift*, 1904, part 4, where Eichberg gives a lucid exposition of the theory of his interesting machine.

and large manufacturers. Now if this common supply can be furnished by one common distribution system, supplying one and the same kind of current, the installations are simplified and current becomes cheaper. With 25 cycles such an extended utilization is said to be possible; it is also said that useful arc-lighting can be obtained. Even if this is so, it must not be left out of consideration that in the case of electric main-railway operation we have to allow for great variations in the load, which may produce variations in the voltage of the order of magnitude of 30 per cent. Under these conditions it will not be possible to obtain satisfactory lighting. There are also other cases of motors which will not be able to stand such variations. It will therefore in many cases be necessary to take into consideration the question of transforming or converting the current into a form more suitable for purposes other than the driving of trains, unless it is preferred to keep the electric main-railway system entirely independent of other applications, and let the latter be met by an own distributing system and an own power station.

It is therefore not advisable to make the decision as to the frequency depend on other projects drawing current from the same power station; as both, the train service as well as the other undertakings, will then be under a certain constraint.

Another consideration of construction is in favour of a low periodicity in the case of the second motor set also.

In a paper dealing with the question of the most suitable periodicity on railways, Eichberg (1) compares the dimensions of a large locomotive motor with 15 and with 25 cycles. According to this, for equal power, the 25 cycle machine has an advantage in weight But the commutator, which is considered the most delicate and costly part of the motor, is better in the case of 15 cycles than of 25. In the former case the commutator is 330 millimetres (1 ft. 1 in.) wide, in the latter 470 millimetres (1 ft. 6 $\frac{1}{2}$ in.) in the former case, the machine has 84 separate brushes, in the latter 148.

These figures show that it is more difficult in the case of this 25-cycle motor also, to overcome the sparking resulting from the short-circuit voltage, than with 15 cycles. In addition the 15-cycle motor is over all 100 millimetres (4 inches) narrower than the 25-cycle motor; this may also be considered an advantage, for in a given available space a more powerful motor can be placed. From the technical operation point of view, the machine with smaller commutator will no doubt be preferred.

The principal reasons, which have been mentioned, are in favour of a low periodicity. The suitable mean is 15. It makes possible the best compromise between the conflicting requirements of turbines, generators and transformers on the one hand, and of conducting systems and motors on the other. Small variations from this mean, in either direction, can be admitted if the object is to generate at a station with the corresponding number of revolutions of the turbines, the 50-cycle rotary current generally used in Germany for light and power installations, and the alter-

(1) *Elektrotechnische Zeitschrift*, 1909, parts 27 and 28.

nating-current for operating railways, or to obtain the alternating-current from 50-cycle rotary-current motors, by conversion. The upper limit is fixed at 16 $^{2}_{3}$ cycles, so as to make it possible, with 1,000, 500, 250, 200, 167, 125, 100 revolutions, to obtain both 50-cycle rotary-current as well as 16 $^{2}/_{3}$-cycle alternating-current, or to convert the one kind of current into the other. The suitable numbers of poles for 50-cycle rotary-current are : 6, 12, 24, 30, 36, 48, 60; for 16 $^{2}/_{3}$-cycle alternating-current, one third these numbers. As lower limit 13 $^{1}/_{3}$ cycles can be taken, so that 50-cycle rotary-current can be obtained at 200 and 100 revolutions with 10 and 20 poles; and 13 $^{1}_{3}$-cycle alternating-current 8 and 16 poles.

It has also to be mentioned that on the section of the Italian State Railway, which is equipped with rotary-current, and on the Simplon line, 15 cycles are also used, in order to make it possible to design suitable motors for the locomotives, without going in for racks.

The *tension in the conductors* has been fixed by the administrations of the German State railways at 10,000 volts. It is true that this is not the maximum at which insulation is still possible, for in Switzerland and in Sweden 15,000 volts are being tried in actual practice. It is however necessary to take into consideration not only the conductors, but also the high-tension appliances on the locomotives and motor cars, which are easier to insulate and maintain when there are 10,000 volts than when there are 15,000 volts; but with 10,000 volts all the requirements of a heavy train service can still be satisfied; the intensities of current which result remain within limits at which the bow collectors work well. With this voltage, there is also an economic distance between the transformers and at the same time the conducting system has enough flexibility to enable an increase to traffic to be dealt with.

IV

Comparative net cost.

Question VIII also asks for a comparison of the cost of continuous-current and of alternating-current (monophase and polyphase).

A comparison between the three kinds of current has been made in the case of the local line Murnau-Oberammergau mentioned in chapter I, and has been published; this deserves special attention inasmuch as alternating current was adopted on this line, although a number of rotary-current appliances were already available (1).

The following three cases were compared :

1° Continuous-current with transformers;

(1) See *Elektrische Kraftbetriebe und Bahnen*, 1905, parts 20 and 21.

2° Rotary-current at 5,000 volts in the transmission and at 800 volts in the overhead conductor;

3° Alternating-current at 5,000 volts in the transmission and at the same voltage in the overhead conductor.

The efficiency, from the dynamo to the driving wheels, was determined at 62 per cent for continuous-current, at 66 per cent for rotary-current and at 71 per cent for alternating-current. If the capital cost in the case of alternating-current is 1, then the corresponding figures for rotary-current and continuous-current are 1·16 and 1·25 respectively.

This, however, does not prove that alternating-current gives the best solution in all cases, assuming always that it is possible to use alternating-current.

In addition we may give as an instance the results calculated in the case of a city railway.

The railway has a total length of 38 kilometres (23·6 miles) of single track. Trains are run at 10-minute intervals; they consist of five carriages with seventy-five seats each. The mean distance between stations is 1·3 kilometres (0·8 mile), the mean speed 33 kilometres (20·5 miles) per hour.

There are three schemes :

1° Continuous-current at 600 volts with third rail. Energy generated as rotary-current and transformers without batteries;

2° Continuous-current at 1,200 volts with catenary conductor; transmission of rotary-current and transformers without batteries;

3° Single-phase alternating-current with catenary conductors for 15,000 volts and transformers at the motors.

Capital cost :

1° 4,800,000 marks (£240,000);

2° 4,500,000 marks (£225,000); as compared with 1°, 300,000 marks (£15,000) or 6·25 per cent less;

3° 4,450,000 marks (£222,500); as compared with 1°, 350,000 marks (£17,500) or 7.3 per cent less.

Working expenses, in so far as they differ, for generation of current, maintenance and renewal of the motor cars and of the line equipment :

1° 603,000 marks (£30,150);

2° 594,000 marks (£29,700); as compared with 1°, 9,000 marks (£450) or 1·5 per cent less;

3° 556,000 marks (£27,800); as compared with 1°, 47,000 marks (£2,350 or 7·8 per cent less.

Scheme 2 is, it is true, cheaper as regards capital cost and working expenses, but not so much that schemes 1 and 2 could not also come under consideration in this special case.

Comparative estimates of the cost of the three kinds of current on sections of main-railways have not been given by the German railway administrations concerned.

Any such calculations depend in most cases on rough estimates if machines, conductors, locomotives, etc., are as yet only projected; if possible, these proposed machines are compared with others which already exist. Thus no very accurate estimate is obtainable. In determining the prices, it is also a material factor if it is a question of manufacturing a few or many articles. Then there are also a whole series of advantages and disadvantages attendant on the different kinds of current, which cannot be immediately expressed in money, but which for technical and working reasons may lead to a preference for one kind of current and to the rejection of another.

The German State railway administrations have decided in favour of alternating-current, for the reasons mentioned in Chapter III. The administrations cannot in this connection be accused of narrow-mindedness, although continuous-current systems have been especially well worked out in Germany; in forming their opinion on the rotary-current system, the administrations had, apart from the cases of trial working mentioned in chapter I, chiefly to refer to installations in other countries. As a matter of fact it is of less importance, to determine by a series of calculations how much one kind of current costs less than another, than to be certain that the selection made will satisfy the requirements of the traffic, that that kind of current will make it possible to utilize the advantages of electric operation fully and completely, and that the electric operation will be cheaper or at least no more expensive than steam working.

In this way for instance, the Bavarian Board of Works has made comparative estimates of the cost of electric operation and of steam operation, on the assumption that alternating-current was going to be used (1).

Two methods were adopted :

In the first method, the maximum price per kilowatt-hour was determined, which would make steam operation and electric operation cost the same. This cost can be determined from the difference between the cost of steam operation and the cost of electric operation without the cost of the electric work. In doing this, the items have to be considered which would be altered if electric traction were introduced. Instances worked out according to this method are given for several lines.

According to the second method, the price per kilowatt-hour is assumed to be known, and the minimum consumption of energy for the economic advisability of the scheme, called the " critical consumption ", is calculated. This consumption corresponds to the minimum amount of traffic required for the economic success of the electric operation.

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(1) See the memoir which has already been mentioned several times, and the *Bulletin of the Railway Congress* for January, 1910.

This method was adopted in order to obtain a general view as to the possibility of extending electric operation to the whole Bavarian State railway system (1).

The figures given in the instances above show that any separate sections of a large railway system only show small advantages in favour of the one or the other system.

When it is a question of introducing electric operation on large connected systems, the decision will always be in favour of alternating-current.

With these explanations, which are based on the answers received to our list of questions, we have completed our consideration of the general questions concerning the present state of the electric operation of trains on the German main-railways.

In the following table, we give some figures about the operations of the electric lines Berlin-Grosslichterfelde and Ohlsdorf-Hamburg Altona-Blankenese and about the projected electric operation of the Wiesenthal line and the Salzburg-Reichenhall-Berchtesgaden line.

We then add some particulars about the improvements which have been made in Germany by the co-operation of manufacturers and of the State Railway administrations, in two of the most important parts of an electrically-operated main railway, namely in the line equipment and the locomotives.

V

Construction and operation of electric railways Berlin-Grosslichterfelde, Hamburg-Altona, Wiesental, Salzburg-Berchtesgaden. — Statistics.

Number in list of questions.	PARTICULARS.	In operation.		Projected.	
		Berlin-Grosslichterfelde.	Hamburg-Altona.	Wiesental line.	Salzburg-Berchtesgaden.
8	Length of the railway, in kilometres (in miles)	9·21 (5·74)	26·66 (16·57)	49·232 (30·592)	40·38 (25·09)
	Number of tracks	2	2	1	1 (on 5·4 kilometres [3·36 miles]). 2.
9	Steepest gradient and its length	6·66 per mil: 0·5 kilometre (0·31 mile).	12·5 per mil: 0·268 kilometre (0·167 mile).	10 per mil: 9·979 kilometres (6·200 miles).	40 per mil, 5·7 kilometres (3·54 miles).
	Minimum radius, in metres (in chains)	300 (15)	250 (12½) at stations 300 (15) in the open country.	300 (15)	180 (9)
	Difference in altitude between terminal stations, in metres	0·4 (1′ 3⅜″)	31·06 (101′ 10″)	165 (541′ 4″) (Basel-Zell). 83 (272′ 4″) (Schopfheim-Säckingen).	116 (380′ 7″) (Salzburg-Berchtesgaden). 269·5 (884′ 2″) (Salzburg-Hallthurn).

(1) See *Bulletin* for January, 1910.

*

Number in list of questions.	PARTICULARS.	In operation.		Projected.	
		Berlin-Grosslichterfelde.	Hamburg-Altona.	Wiesental line.	Salzburg-Berchtesgaden
10	Maximum permissible wheel-load, in tons (in English tons)	8 (7·9)	8·5 (8·4) (Ohlsdorf-Altona). 7·6 (7·5) (Altona-Blankenese	7 (6·9)	7 (6·9)
	Maximum permissible speed, in kilometres (in miles) per hour	50 (31)	50 (31)	70 (43·5)	Salzburg-Freilassing: 80 (49·7) Freilassing-Reichenhall: 70 (43·5). Reichenhall-Berchtesgaden 40 (24·9).
	Weight of rails, in kilograms per metre (in lb. per yard)	41 (82·65)	33·4 (67·33) / 43·43 (87·55) about	36·2 (72·97) / 43·8 (88·30)	31·2 (62·90)
	Length of rails, in metres	15 (49′ 3″)	12 (39′ 4″) / 15 (49′ 3″)	9 (29′ 6″) / 18 (59′) about 12 (39′ 4″).	9 (29′ 6″) et 12 (39′ 4″).
31	Capital cost of own power station (in marks (in pound sterling)	Foreign power station.	3,756,000 (£187,800)	Foreign power station.	2,900,000 (£145,00
33	Kind of current at power station, voltage, frequency	Continuous-current, 550 volts.	Alternating-current 6,300 about 30,000 volts, 25 cycles.	Rotary-current, 6,800 volts, 50 cycles 10,000 volts, 15 cycles.	Rotary current 10,000 volts, 15 cycles.
38-39	System of distribution	Third rail.	Overhead wire.	Overhead wire.	Overhead wire
	Cross-section on main-line, in square millimetres (in circular-miles)	Normal cross-section 8 (41 kilog. per metre [82.65 lb. per yard]).	90 (177,620	100 (197,350)	100 (197,350)
	Conductivity	8	57	57	57
	Strength	...	38 (54,050)	38 (54,050)	38 (54,050)
44	Length of conductors at sidings	0·9 (0·56) (0·2 kilometre [0·12 mile] in sheds).	12·3 (7·64)	35 (21·75)	6·5 (4·04)
	Cross section	Normal cross-section, 8.	90 (177,620)	70 (138,150)	80 (157,880)
46	Kind of current in conductors	Continuous-current, 550 volts.	Alternating-current, 6,300 volts, 25 cycles.	Alternating-current, 10,000 volts, 15 cycles,	Alternating-curr 10,000 volts, 15 cycles.
47	Number of locomotives	...	...	12	6
48	Number of motors cars	24	86	...	2
49-50	Number and output of motors	2 × 100	3 × 115 and 2 × 180	2 × 475	...
65	Capacity of motor cars	Room for 79 third-class passengers.	128 seats with standing room, 190 passengers.	...	165 seats.
66	Capital cost of vehicle ready for service in marks	46,250 (£2,312·10 s.) (third-class carriage).	100,000 (£5,000)	...	...

Number in list of questions.	PARTICULARS.	In operation.		Projected.	
		Berlin-Grosslichterfelde.	Hamburg-Altona.	Wiesental line.	Salzburg-Berchtesgaden.
67	Number of trains per day	206 passenger trains (196 on sundays).	420	60 passenger trains. 22 goods trains.	36 passenger trains. 4 goods trains.
				82	40
	Number of train-kilometres (train-miles) per year	692,101 (430,059)	2,011,960 (1,250,197)	430,600 (267,367) 93,801 [illegible]	234,942 (in the year 1910).
				524,400 (325,853)	
	Ton-kilometres (English ton-miles)	111,858,390 (68,109,040)	247,979,467 (151,656,369)	122,930,000 (75,180,095)	28,686,519 (17,543,764) (in the year 1910).
70	Maximum load at power station in kilowatts	1,800	5,100 (on weekdays). 4,300 (on sundays).	2,500	2,500
	Mean load per day (of 24 hours) with maximum traffic	600	1,900	1,014	500
	Ditto with minimum traffic	400	1,540	...	250
	Useful kilowatt-hours supplied to the railway distribution network	4,097,700	8,477,078 (from 1 October 1908 to 31 Mars 1909).	3,500,000	1,760,090 (in the year 1910).
72	Cost per kilowatt-hour at own power station	...	5·24 (0·629)	...	2·91 (0·349)
	Additional cost for feeder lines, including transformers at feeding points	...	0·48 (0·058)	...	0·59 (0·071)
	Additional cost for overhead equipment of line	...	1·22 (0·146)	...	2·62 (0·314)
			6·94 (0·833)		6·12 (0·734)
73	Cost per kilowatt-hour when supplied from outside, in pfennigs (in pence)	7 (0·840) at power station.	...	1·5 (0·180) at power station if 8,000,000 kilowatt-hours are taken.	...
	Number of kilowatt-hours purchased per annum	4,097,700	...	8,000,000	...
74	Total amount for maintenance, interest on capital, and amortization of electric rolling stock	212,000 (£10,600)	461,000 (£23,050)	106,000 (£5,300)	96,260 (£4,813)
75	Watts-hours consumed per gross ton-kilometre (per gross English ton-mile):				
	a) Measured at power station	36·1 (59·0) not including lighting.	52·8 (86·3) including lighting and heating.	28·4 (46·4) not including lighting and heating.	59 (96·5) including lighting and heating.
	b) Measured at current collector	33·5 (54·8) not including lighting.	38 (62·1) not including lighting and heating.		55 (89·9) including lighting and heating

Number in list of questions.	PARTICULARS.	In operation.		Projected.	
		Berlin-Grosslichterfelde.	Hamburg-Altona.	Wiesental line.	Salzburg-Berchtesgaden.
76	Working costs per gross ton-kilometre (per gross English ton-mile). . . .	0·512 (0·1004)	0·727 (0·1427)	0·4 (0·0785)	0·798 (0·1565)
	Separate items :				
	1. Cost of energy, at power station.	0·256 (0·0502)	0·277 (0·0544)	...	0·173 (0·0339) at the rate given under No 72.
	2. Feeders and transformers. . .		0·025 (0·0049)	...	0·035 (0·0069)
	3. Overhead equipment	0·027 (0·0053)	0·064 (0·0126)	...	0·156 (0·0306)
	4. Maintenance of electric rolling stock	0·164 (0·0322)	0·274 (0·0538)	...	0·331 (0·0649)
	5. Wages bill of train staff (locomotive staff)	0·040 (0·0078)	0·043 (0·0084)	...	0·099 (0·0194)
	6. Costs of stores for the service .	0·025 (0·0049)	0·044 (0·0086)	...	0·004 (0·0008)
		0·512 (0·1004)	0·727 (0·1427)		0·798 (0·1565)
	Costs which could be paid per kilowatt-hour if electric traction is not to be dearer than steam traction	...	...	...	4·9 (0·958)

VI

Equipment of the line for electrically-operated main railways.

In the cases of electrically-operated main railways that we are dealing with, the so-called " third rail " need not enter into consideration. That is for use on elevated and underground lines, city lines and short suburban lines; all lines which can be operated by means of continuous-current of not too high voltage.

Main railway operation requires an overhead conductor for the alternating-current.

This overhead conductor, which brings the current to the vehicle, has to satisfy conditions materially more difficult in the case of electrically-operated main-railways than in the case of tramways or minor railways. The ordinary arrangement in the case of the latter consists of a hard copper wire, supported from cross wires or brackets and insulated; but that is not suitable in the former case as owing to the materially-higher speeds the collector can not adjust itself to the varying height of the conductor. The collectors would not always remain in contact with the con-

ductor, and consequently formidable arcs would be formed, particularly as it is a question of transmitting large quantities of energy. These arcs would on the one hand damage both the collector and the conductor, and on the other hand produce dangerous current rushes and overloads in the motors.

On main railways, the conductor must have as uniform and level a position as possible and must be fitted with some device for automatically compensating any changes of length resulting from variations in the temperature.

Then also it is important to insulate the conductor from the earth. As owing to the great distances over which energy has to be transmitted in the case of main railways the voltage must be high, special attention has to be devoted to good and durable insulation. The insulation must in all cases be double, and such that one insulator can by itself safely fulfil all the conditions necessary.

A second condition which must be observed as regards the conductor and its support, is that there must be no soldered joint in the conductor, as its strength might otherwise be impaired by the soldering operation. This condition is also necessary in order that putting up and repairing the conductor should only take a short time. This condition is easily satisfied because the usual trolley arrangement as used in tramways is out of the question, and only collectors of the bow or roller form can be used. The conductor has a grooved section.

The conditions mentioned can be satisfied comparatively easily in the case of single-phase conductors, such as are required for the alternating-current system selected in Germany. They have led to the development of a multiple-suspension system, in which the conductor does not merely depend on its own intrinsic strength, but in which auxiliary supporting wires of greater strength are also used, so as to ensure a nearly-horizontal position of the conductor whatever the temperature may be.

Of the systems of construction developed in Germany, two have up till now been used in actual practice, one by the *Allgemeine Elektrizitäts-Gesellschaft*, the other by the *Siemens-Schuckert Works*. These two firms have solved the problem in different ways.

As early forms of single-phase multiple-suspension conductors we may mention those tried by the administration of the Prussian State Railway conjointly with the *Allgemeine Elektrizitäts-Gesellschaft* in the years 1904 and 1905 on the experimental section Niederschönweide-Spindlersfeld, when the first Winter-Eichberg alternating-current motors were tested as to their suitability for heavy-train traffic [1].

The overhead conductor of the Siemens-Schuckert Works.

The Siemens-Schuckert overhead equipment consists of three wires, one above the other (fig. 1) : a grooved conducting wire *a* of hard copper (on main lines a

[1] See *Zeitschrift des Vereins deutscher Ingenieure*, 1904, part 9.

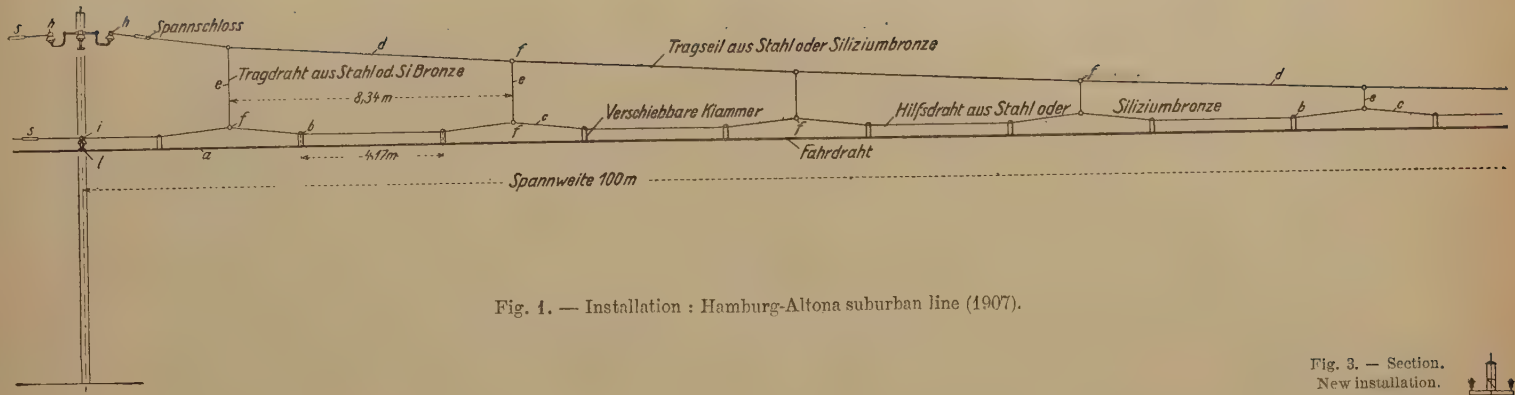


Fig. 1. — Installation : Hamburg-Altona suburban line (1907).

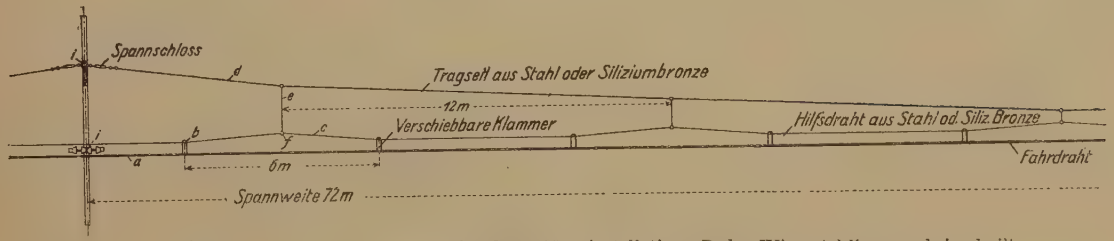


Fig. 2. — New installation : Baden-Wiesental line now being built.

Fig. 3. — Section. New installation.

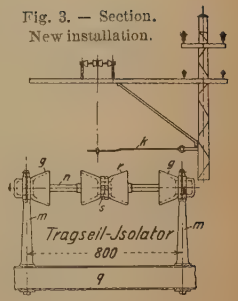


Fig. 4.

Figs. 1 to 4. — Multiple suspension for main railways. Design : Siemens-Schuckert Works, of Berlin.

Explanation of German terms : Spannschloss = Strainer. — Tragdraht aus Stahl oder Siliziumbronze = Suspension wire of steel or silicon bronze. — Spannweite = Length of span. — Tragseil aus Stahl oder Siliziumbronze = Supporting rope of steel or silicon bronze. — Verschiebbare Klammer = Movable clip. — Fahrdraht = Conducting wire. — Hilfsdraht aus Stahl oder Siliziumbronze = Auxiliary wire of steel or silicon bronze. — Tragseil-Isolator = Insulator of supporting rope.

cross-section of 100 square millimetres (197,350 circular mils) is usual on account of the larger quantities of energy and more especially on account of the strength) and an auxiliary supporting wire *c* of steel or of silicon bronze and a supporting wire rope *d*, also of steel or of silicon bronze.

The conducting wire *a* is hung by means of special clips *b* from the auxiliary supporting wire *c* which is vertically over it, and this is again hung by the suspension wires *e* from the wire rope *d* above.

The steel wire rope consists of 7 wires and has a cross-section of 50 square millimetres (98,675 circular mils); the auxiliary supporting wire has a diameter of 6·5 millimetres ($^{17}/_{64}$ inch) and the suspension wire one of 5 millimetres ($^{3}/_{16}$ inch). The material used for the two former has an ultimate tensile strength of 70 kilograms per square millimetre (99,560 lb. per square inch) that used for the suspension wires has one of 45 kilograms per square millimetre (64,000 lb. per square inch). As regards the dimensions, if silicon bronze is used, see below.

The clips *b* are so arranged, that they are rigidly fixed to the conducting wire *a*, while the auxiliary wire *c* has enough play to allow displacement of the clips on that wire when the conductor varies in length. The clips *b* are everywhere equally spaced. The distance between them depends on the speed of running, and is on the average 6 metres (19 ft. 8 in.). As the conducting wire is supported at so many points, there can be only very little sag.

The suspension wires *e* are twice as far apart as the clips *b*; they are connected both with the wire rope *d* and the auxiliary supporting wire *c* by fixed clips *f*.

Finally, the wire rope *d* is supported at each pole by the insulators *h* in such a way that it only extends from pole to pole, while the supporting wire *c* and the conducting wire as a rule extends right through, without break of continuity at the poles.

The wire rope insulators *h* consist of three bell-shaped insulators, two of which with their bent supports rest on the malleable iron cap of the third. The support of the latter is fixed to the bracket of the pole (see sketch, fig. 9). Corresponding to their insulation value, two insulators are placed in parallel, and in series with the third.

In order to compensate for alterations in length produced by changes of temperature, the wire rope and the supporting wire are both fitted with strainers S, operated by hand; the wire rope has one in each span, but the supporting wire has them at greater intervals. The conducting wire is fitted at every 1·5 kilometres (0·93 mile) with an automatic gravity stretcher actuated by weights.

As the ends of the wire rope are rigidly connected with the poles and the strainers can only be operated by hand, its sag is less at lower temperatures and greater at high temperatures. Consequently the auxiliary wire and the conducting wire, which hang from the wire rope, will be at a greater height above rail-level when it is cold and at a less height when it is warm. The height of the conducting wire

will thus vary a little, according to temperature. To keep the height absolutely constant is not possible, and is also not necessary. The important point is that the conducting wire is always subjected by the automatic stretcher to the same tension whatever the temperature, and it is nearly in a horizontal position, without sag. In order that the bow collector may remain at this height, it is necessary to take care that the different points of support are as nearly as possible equal distances apart. If the poles are spaced irregularly, the sag of the wire rope will vary in the different spans, and when temperature varies the conducting wire will not be kept so horizontal.

An important device in the whole arrangement is the automatic stretcher, which was first used by the Siemens-Schuckert Works on the Hamburg-Altona suburban line. Such a device is absolutely necessary for a main-railway installation, as when there is much traffic it is impossible to adjust the conducting wire by hand.

The arrangement of the automatic stretcher, as constructed by the Siemens-Schuckert Works, is shown in figures 5 to 8 and 10; in this case, it is also used for dividing the sections and anchoring.

While the poles on the straight line are kept as far apart as possible (up to 70 metres [76 yards] and more, they are 12 metres (13 yards) apart at the division.

The conducting wire a_1 coming from the one side, below the supporting rope d_1, is continued nearly to the pole m_2; the conducting wire a_2 coming from the other side below the supporting rope d_2, is continued at a horizontal distance of 300 metres (328 yards) from a_1 to the pole m_1. The conducting wires rise a little, so that the bow collector may slide past without hindrance.

The auxiliary supporting wire only extends to the poles m_1 and m_2 and is separated from them by the double insulator i_3. In the stretching section itself, this wire is replaced by the steel tubes s_1 and s_2, the former hanging from the supporting rope d_1, and the latter from the supporting rope d_2.

The conducting wire a_1 is hung from the first steel tube s_1 by means of the two movable clips $b_1 b_1$, and is connected at its end with a chain K_1. Between the conducting wire and the chain, the double insulator J_1 is interposed. The chain passes over the sheaves $K_1 r_1$ to a weight hanging at the side of the pole, which subjects the wire a_1 to the same tension whatever the temperature may be. The other conducting wire a_2 is hung in the same way from the steel tubes s_2 and subjected to a uniform tension by a chain K_2 and a weight. In order to show the proper connections between the conducting wire, the steel tube and the supporting rope more clearly, a separate drawing of the parts belonging together, for the line coming from the left, is shown in figure 6.

The live parts of the one conducting system are insulated from the iron poles by the insulators h_1, i_1, J_1, those of the other by the insulators h_2, i_2, J_2.

As the two conducting wires do not touch each other and are insulated from the poles, the overhead conductor is divided at this point.

If the stretching gear is not intended to divide as well, high-tension horn switches

Fig. 5.

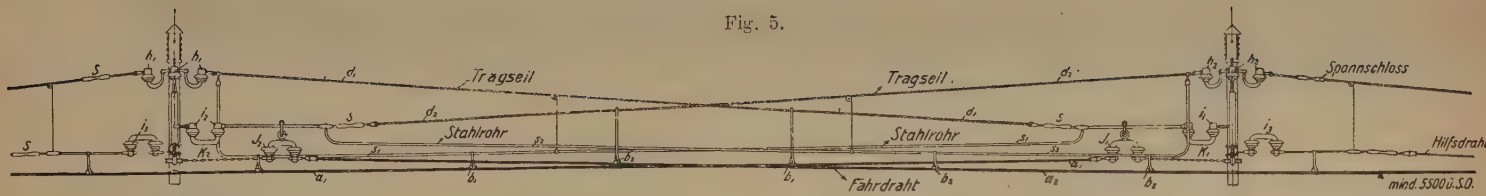


Fig. 6.

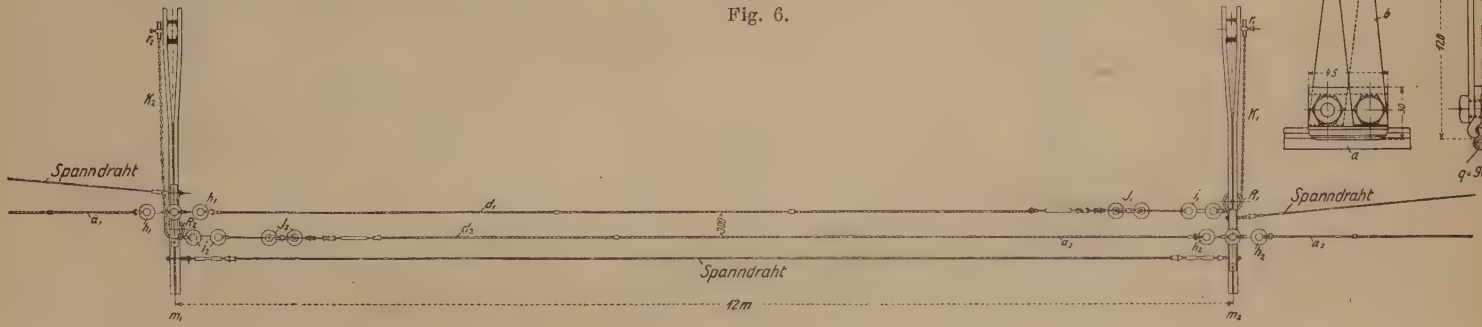
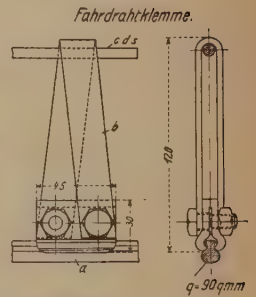


Fig. 7.

Fig. 8.



Figs. 5 to 8. — Division into sections with automatic stretching of the conducting wire. Design : Siemens-Schuckert Works, of Berlin. Installation : Hamburg-Altona suburban line.

Explanation of German terms : Hilfsdraht = Auxiliary wire. — Stahlrohr = Steel tube. — Tragseil = Supporting rope. — Fahrdraht = Conducting wire. Mind. 5500 ü. S. O. = At least 5500 millimetres (18 ft. 9/16 in.). Fahrdrahtklemme = Conducting wire clamp. — Spanndraht = Auxiliary wire. — Spannschloss = Strainer.

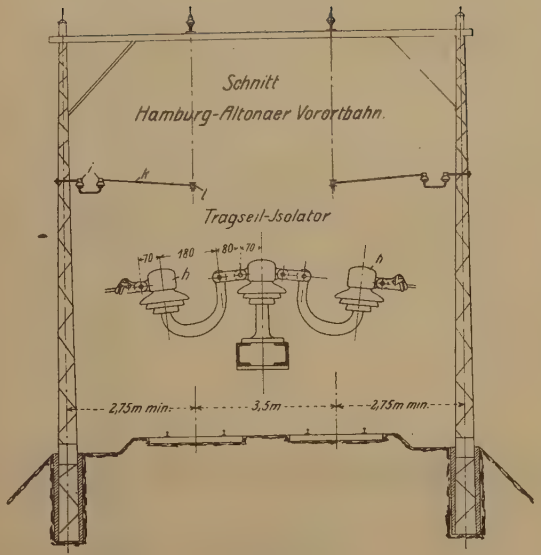


Fig. 9.

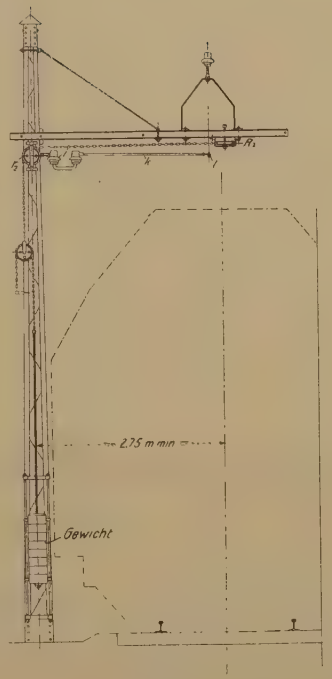


Fig. 10.

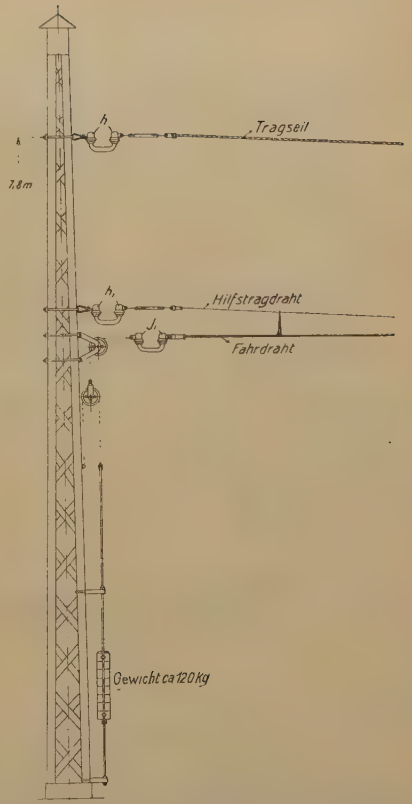


Fig. 11. — End with automatic stretching of conducting wire. Design : Siemens-Schuckert Works, of Berlin.

Explanation of German terms : Schnitt = Section. — Hamburg-Altonaer Vorortbahn = Hamburg-Altona suburban line. — Tragseil-Isolator = Insulator of supporting rope. — Gewicht = Weight. — Tragseil = Supporting rope. — Hilfstragdraht = Auxiliary wire. — Fahrdraht = Conducting wire. — Gewicht ca. 120 Kg. = Weight about

are interposed between the two conducting systems, to connect the conducting wires.

At the end of the conducting system the supporting rope, the auxiliary wire and the conducting wire terminate at the pole, the conducting wire being connected with automatic stretching gear. The construction of this automatic stretching gear and its connection with the conducting wire is shown in figure 11.

An important point is also the staying of the supporting system at the poles. The rope is held at all the points of support by the insulation *h*. The auxiliary wire and the conducting wire would be able to swing too much laterally when there was much wind unless they were supported further. In order to prevent such swinging, the conducting wire and the auxiliary supporting wire are held at each pole by an insulated stay *k* (figs. 9 and 10) fixed to the pole. This consits of a piece of gas pipe, insulated from the pole by the double insulator *i* and connected with the conducting wire by the clip *l*. It is fixed to the insulator in such a way that it can revolve, so that it can give vertically under the pressure of the bow collector. In doing this, regard has to be paid to the position of the conducting wire relatively to the centre line of the track, for the wire should form a zigzag line in plan, so that the bow may become worn over a large surface. At curves, these stays are arranged to work in tension only.

It has also to be mentioned that in consequence of the method of suspension adopted, the supporting gear remains undamaged should the conducting wire break. The conducting wire can move freely with the sliding clips *b* until these are stopped by the stretching gear. The closer the clips are together, the less a broken end can hang down.

If the auxiliary wire breaks, the suspension wires prevent it from hanging down far. Only if the wire rope, or one of its insulators breaks, can the whole installation come down. But the cross-section of the rope provides for a large factor of safety, so that it is unlikely to break.

The system of supporting the conducting wire, shown in figures 1 and 5 to 11, has been in use on the Hamburg-Altona suburban line since 1 October 1907. The second insulation was added subsequently. The system has given good results. A newer system, proposed for the Wiesental line in Baden, is shown in figures 2 to 4. Instead of delta bell insulators with malleable caps (shown in figure 9), the tube insulators shown in figure 4 are used for the supporting wire rope. These are so constructed and fixed that they only work in compression, while the insulators shown in figure 9 are also subjected to bending stresses which may break them.

The tube insulator *r* is placed on a gaspipe *n*; the two ends are held in the bell-shaped insulators *g*, which are supported by the upright *m*. The latter are fixed by screws either to the cross piece *q* or to the bracket. The rope on each side is led round the bell *s*, which is placed on the tube insulator *r*. The same arrangement of tube and bell insulators is also used for fixing the conducting wire laterally to the poles (see fig. 3).

Fig. 12.

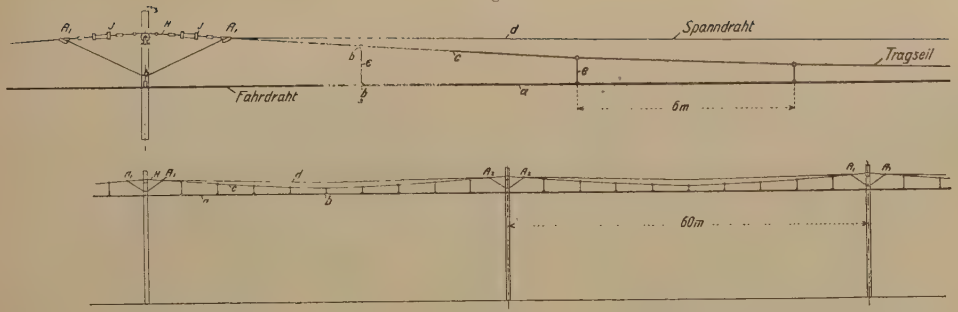


Fig. 13.

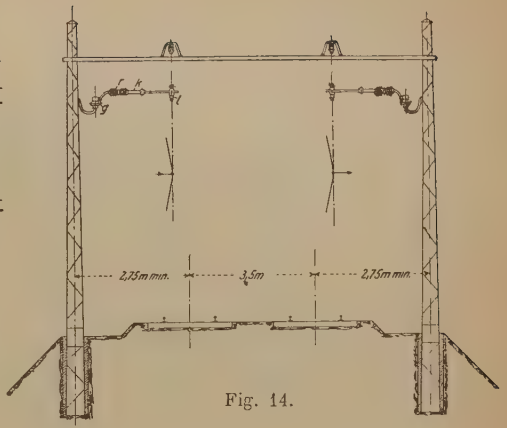


Fig. 14.

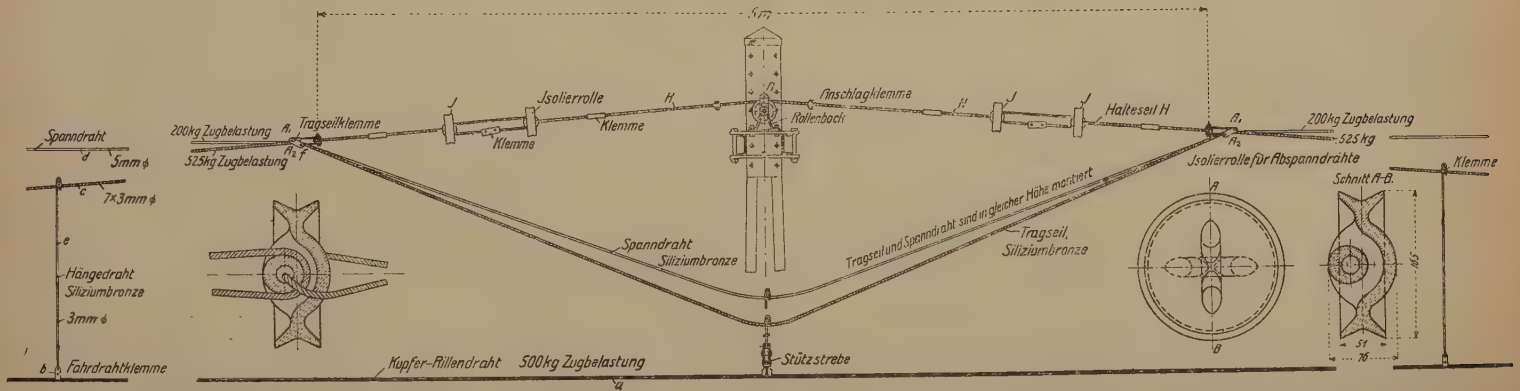


Fig. 15.

Figs. 12 to 15. — Multiple suspension for main railways. — Design : Berlin Elektrizitäts-Gesellschaft, applied for purposes of trial on the Oranienburg line. — Decided upon for the Wiesental line (under construction).

If one of the insulators breaks, the rope cannot fall to the ground, for it is supported by the bell and the gaspipe. This design thus forms a great guarantee for the safety of the whole installation.

The design of the Wiesental insulators can accordingly be considered a material improvement on the design of those used on the Hamburg-Altona suburban line.

The overhead conductor of the " Allgemeine Elektrizitäts-Gesellschaft ".

The new system which resulted from the work carried out on the Spindlersfeld experimental line and the Oranienburg experimental line of the Prussian State Railway during 1908-1909, is shown in figures 12 to 18. The conducting wire *a* (fig. 12) is supported by the wire rope *c* and the auxiliary wire *d*. The two latter are made of silicon bronze. The rope has a cross-section of 43 square millimetres (84,860 circular mils), the auxiliary wire a diameter of 6 millimetres ($^{15}/_{64}$ inch). They are both made of material having an ultimate tensile strength of 75 kilograms per square millimetre (107,670 lb. per square inch) and a conductivity of 40 per cent; the suspension wires have an ultimate tensile strength of 46 kilograms per square millimetre (65,425 lb. per square inch) and a conductivity of 98 per cent. The supporting rope *c* (fig. 12) is immediately above the conducting wire *a* and extends without break of continuity at the poles. The auxiliary wire *d* is above the rope, but has less sag than the latter. This auxiliary wire is only connected at the two points A_1 and A_2, near the poles, rigidly with the rope *c* (figs. 12 and 13).

The conducting wire *a* is hung directly from the rope *c* by the simple suspension wires *e* having fixed clips *bb* at their ends. The auxiliary wire *d* and the supporting rope *c* are connected at the points A_1A_1 or A_2A_2 with the holding rope H which runs over a sheave fixed to the bracket of the pole, as shown in figure 15 on a larger scale. The supporting rope and the auxiliary wire pass under the bracket, so that there is no break in their continuity.

The holding rope H is insulated on each side of the pole from the rest of the system by the two insulating disks JJ. These insulators are shown in figure 15 on a larger scale.

As the holding rope runs over a sheave on the pole, the points A_1A_1 and A_2A_2 are not rigidly fixed, but can easily move and transmit movements and alterations of tension from one given field between two poles to the neighbouring field.

In order to have a uniform tension on the system, however much the tension may vary, automatic gravity stretchers are provided at about every 1,000 metres (1,090 yards). The point of support equally distant between two such stretchers is rigidly fixed.

The auxiliary wire has, as figures 12 and 13 show, less sag than the supporting rope, and it is intended to keep the conducting wire as far as possible at the same height, however much the temperature may vary. In order to make this clear, we will consider what happens in one field when there is a change of temperature.

If, for instance, it becomes colder, the auxiliary wire contracts and lifts the weights attached at its ends. But this contraction of the auxiliary wire at the same time makes the connecting points A_1 and A_2 of the supporting rope, within one and the same field, approach each other. The supporting rope, which like the auxiliary wire, is made of silicon bronze and has consequently the same coefficient of expansion, is shortened by a corresponding extent by the cold. If the points A_1 and A_2 were rigidly fixed, their sag would be reduced. The consequence would be that the suspension wires c and with them the conducting wire a, would be raised to a corresponding extent. But as points A_1 and A_2 approach each other in consequence of the greater change of tension in the auxiliary wire, the sag of the supporting rope between A_1 and A_2 is again increased and the suspension wires together with the conducting wires are thereby lowered.

As this lowering approximately equals the raising, the conducting wire does not change its height when it becomes colder; it remains horizontal.

If it becomes warmer, the auxiliary wire d expands, the weights move and the points A_1 and A_2 in the same field move further apart.

The supporting rope C also becomes longer, as it is warmer, and its sag increases. If the points A_1 and A_2 were rigidly fixed, the suspension wires and the conducting wire would be lowered. But as they are moved apart, the former sag is restored and the conducting wire also does not change its height when it becomes warmer.

Consequently the arrangement of the auxiliary wire together with the automatic stretching gear produce this result that the conducting wire between two stretchers always keeps, sufficiently approximately, at the same height above the level of the rails.

We will now describe the automatic stretching gear; particulars are shown in figures 16, 17 and 18.

The conducting wire a_1 coming from the one side, its supporting rope c_1, and auxiliary wire d_1, extend to a strutting appliance S (see fig. 16). Behind this the three wires are joined together at the point k_1 to the rope s_1 (see fig. 17, on which the arrangement for the wires coming from the left is alone shown). This rope s_1 is kept stretched by the weight G_1 on the left side of the pole, which acts by means of other steel ropes s'_1 and s''_1 and a pulley gear. The three conductors are insulated from the pole by two pairs of insulators placed one behind the other.

In the same way the conducting wire a_2 coming from the other side, its supporting rope c_2 and the auxiliary wire d_2 extend to the strutting appliance S joined together at the point k_2, and kept stretched by the weight G_2 at the other pole, which acts by means of the steel ropes s_2, s'_2 and s''_2, and a pulley gear. A side view of the whole stretching gear is shown in figure 16, and a plan of it, for a double-track railway, is shown in figure 18; the scale of heights in figure 16 is greater than the scale of lengths. so as to show more clearly the position of the wire.

The strutting appliance, which is to keep the two systems overlapping at the proper distances from each other, is made in two different forms.

Fig. 16.

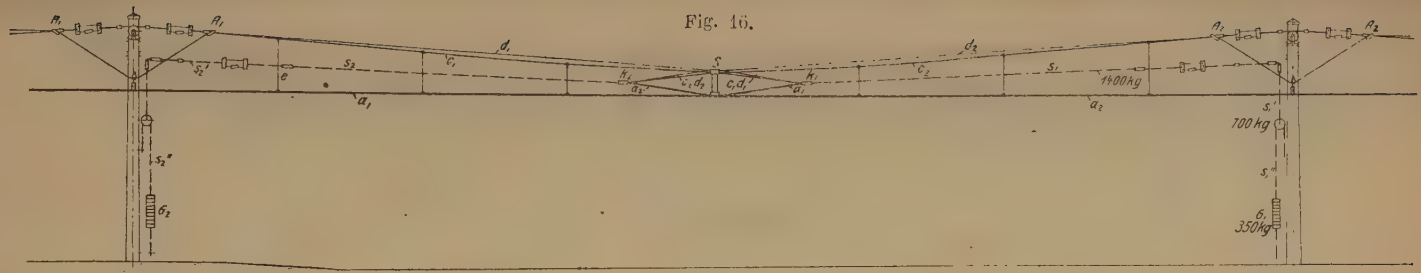


Fig. 17.

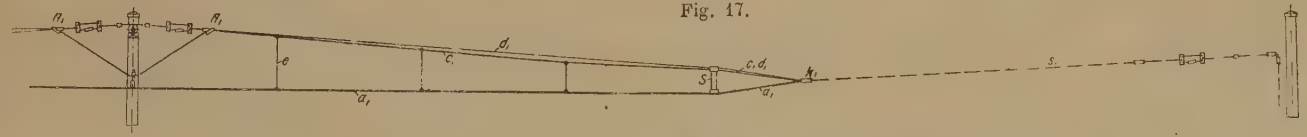
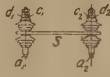


Fig. 20. Spreize für Nachspannvorrichtung mit Streckenisolierung



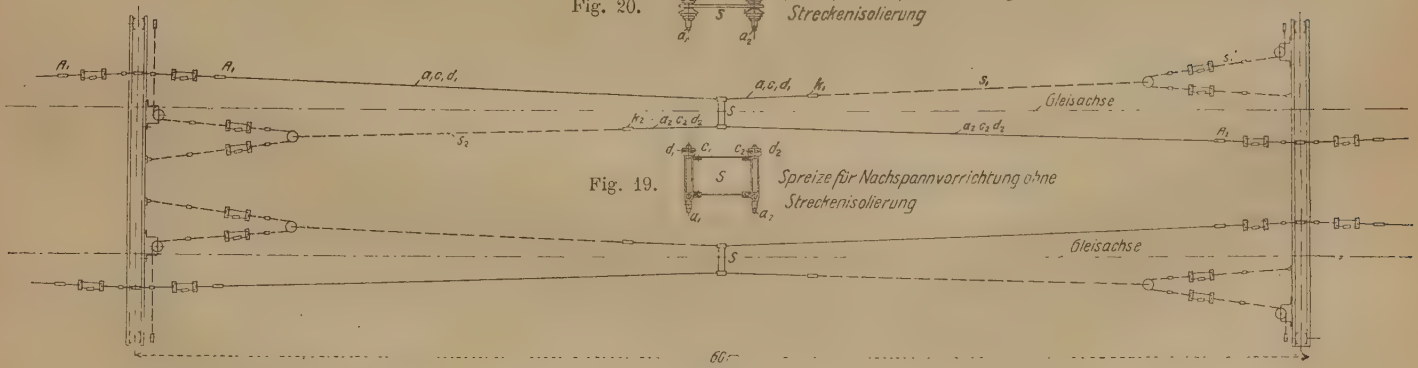


Fig. 19. Spreize für Nachspannvorrichtung ohne Streckenisolierung

Fig. 18.

Figs. 16 to 20. — Stretching appliance and division into sections. Design : Allgemeine Elektrizitäts-Gesellschaft of Berlin, 1909.

Explanation of German terms : Spreize für Nachspannvorrichtung mit Streckenisolierung = Strut for stretching gear, with insulation of sections. Spreize für Nachspannvorrichtung ohne Streckenisolierung = Strut for stretching gear, without insulation of sections. — Gleisachse = Centre line of track.

If the conduction is to be continuous at the stretchers, the strutting appliance is made with cross-connections, to conduct the current from the one wire to the other. This is illustrated in figure 19. If, however, there is to be a division at the stretchers, it is made with a double insulation (fig. 20).

It has also to be mentioned that stop clamps are fixed to the holding rope H (fig. 15), which take against the blocks on the poles should the rope give too much. This prevents the points A_1A_2 where the holding rope is connected with the other gear, from being too much displaced.

A pin at the top of the blocks prevents the holding rope H from coming off the sheave.

The conducting wire is stayed laterally from the mast by a steel tube *k* (fig. 14), which is doubly insulated from the mast, firstly by the bell insulator *g*, secondly by the grooved insulator *r*. The first has cemented on it a malleable-iron cap; the stay is fixed so that it can turn about this. The holder proper *l* can slide on the steel tube and is clamped when the conducting wire is in the position desired. The centre line of the conducting wire and the pivot of the stay are at the same height.

In order to prevent any swinging of the supporting rope and auxiliary wire under the brackets, where they are not stretched, they are connected with the conducting wire by a suspension wire (fig. 15).

The conducting wire and its supporting gear is everywhere insulated from the earth by a double insulation. The disk insulators generally used are similar to those constructed by the General Electric Company of Schenectady, U. S. A. They are only acted on by compressive stresses and afford great safety against breakage. Should such occur, it would be impossible for the gear to fall as the different parts acting as supports are interconnected (see fig. 15).

The use of four insulators, two being always placed in series and two in parallel, is an improvement on that of three insulators, two placed in parallel and the pair placed in series with the third; it has the advantage that all the insulators have to resist the same tension. If three insulators are used, the two first have to take $^1/_3$ and the last $^2/_3$. Now if the last, which is subjected to greater tension, breaks, it is possible that the two other insulators, which otherwise are subjected to a lower tension, will not be able to resist the sudden increase of tension. Hence, if four insulators are used, there is less risk of a short circuit in consequence of too great stresses on any of the insulators.

The peculiar arrangement of the supporting rope and the auxiliary wire makes it necessary to break their continuity at each pole in order to insert insulators. Consequently, when such an installation is to be put up, the whole supporting gear, together with the conducting wire, can be prepared during the day and laid along the track; then in the intervals when there is no traffic, even at night, it can be hauled up and fixed to the brackets.

The installations described are intended for use with 10,000-volt current.

Working results.

During the working of the Hamburg-Altona suburban line, it was found that single insulation did not suffice. At first, the insulator standing up vertically from the crossbar of the poles was the only one; the two delta insulators resting on the malleable-iron cap of the first were only added later on, as it was found the insulation was defective.

It has also been found that for the time being, porcelain is the safest insulating material. Covering the insulator support with iron-rubber and similar materials did not give good results.

Moreover, experience has shown that steel is not a good material for the supporting ropes, the auxiliary wires and the suspension wires, on sections where steam trains are still running, especially in covered stations, where locomotive smoke accumulates; for in such places, steel is very liable to rust. The result would be great uncertainty, very high cost of maintenance and disagreeable interruptions in the service. In all places therefore where quick rusting is at all likely, silicon bronze should be used for these parts. Even if the capital cost is increased by the use of this material, it is safer and also increases the conductive cross-section considerably as compared with steel.

When conditions are such that quick rusting is probable, malleable iron has also not given good results. In such cases gun-metal is to be preferred.

The conducting wire should be at a height of not less than 5·5 metres (18 feet) above rail-level, but 6 metres (19 ft. 8 in.) at stations. On lines where steam trains still run, a height of 5·2 metres (17 ft. $^3/_4$ in.) was found to be too small, as the administration of the Prussian State Railway found during its experience on the Hamburg-Altona suburban railway, as if the locomotive tools were handled carelessly, the conducting wire might be touched.

Now although there would be a saving in the capital outlay on the poles if the conducting wire were placed lower, the greater safety is the decisive factor in this question. The opinion has been expressed that the height of the conducting wire should not be less than 6 metres (19 ft. 8 in.) even in the open country. At yards the conducting wires above loading tracks must even be higher, or else it must be possible to switch off the current from such sections.

Then also the distance between the poles and the centre line of the track should not be reduced to the minimum the building and traffic regulations allow, in order to prevent the permanent way men from incurring risks. There should be room enough for a man between the loading gauge and the furthest projection of the pole.

The multiple-suspension system makes it possible to have the poles much further apart than in the case of the ordinary suspension. The distance apart which corresponds to a minimum capital outlay may on the straight be up to 100 metres (109 yards). A suitable distance is 75 metres (82 yards), as then the wind pressure does not displace the wire too much. We are assuming that flat poles (made of

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two channel sections) or square poles (made of four angle-irons) are used, set in concrete footings. Poles made of joist section, with broad flanges (Grey section) would cost less for maintenance than lattice poles; but it has been found that their prime cost is too high as too much metal is required. For the size of the cross-section, which is determined by the maximum stress at the foot of the pole, is much too great at the top.

Wooden poles are out of the question on main railways. Reinforced concrete poles have not been tried in Germany for railway work.

On the Baden-Wiesental line, which will be equipped partly on the A. E. G. and partly on the S. S. W. systems, the poles in the former case will be 60 metres (65 yards) apart; on curves with a radius of from 240 to 450 metres (from 262 to 492 yards) the wire will be pulled laterally at one point. In the latter case, the poles on straight sections will be 72 metres (79 yards) apart and on the curves they will be placed closer together, according to radius.

The position of the poles at the stations is a matter of considerable importance. Up to four tracks and more are spanned very successfully on the Hamburg-Altona suburban line by the use of light trusses. At small stations, the tracks will everywhere require conducting wires over them. At large stations with many shunting lines, the capital outlay will be very great and the utilization of the installation will be very poor. In such cases it has to be considered whether it will not be cheaper to use an accumulator locomotive or a steam locomotive for carrying out the shunting operations.

For main lines, a cross-section of 100 square millimetres (197,350 circular mils) has been accepted for the conducting wire; the conductivity being 57 at 15° C. (59° Fahr.) and the ultimate tensile strength 38 kilograms per square millimetre (54,050 lb. per square inch).

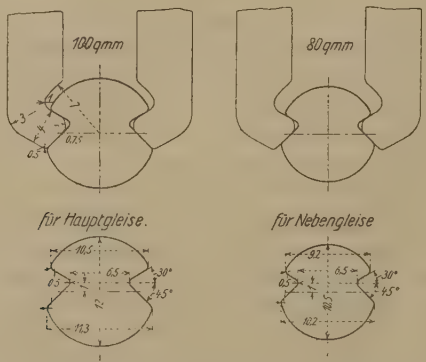

Fig. 21. — Cross-section of conducting wire, Bavarian State Railway.

Explanation of German terms : Für Hauptgleise, für Nebengleise = On main lines, on sidings.

Such a large cross-section is advantageous not only from the point of view of the running loss, but more especially from that of durability. Cross-sections of different shapes are used. That used on the Hamburg-Altona suburban line is shown in figure 8; that used on the Bavarian State Railway, in figure 21. The latter has a circular section with two lateral grooves, which the clamps can take into, so that the wire cannot twist. The centre of gravity of this section nearly coincides with the centre of the circle.

An important point in the line equipment is the question of the rail bonds, for which no generally-satisfactory solution has yet been found. It is doubtful whether, as many assert, rail bonds may be entirely dispensed with in the case of continuous-current railways.

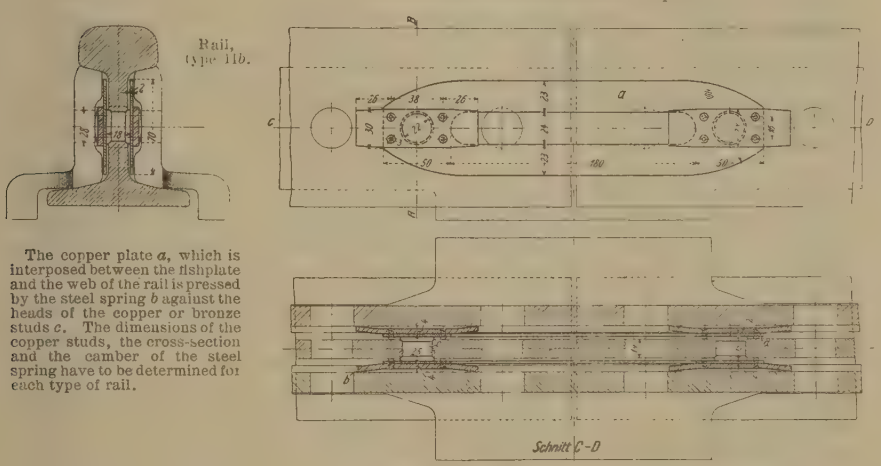
Section A-B.
Side view after removal of fishplate.
Rail, type 11b.
The copper plate a, which is interposed between the fishplate and the web of the rail is pressed by the steel spring b against the heads of the copper or bronze studs c. The dimensions of the copper studs, the cross-section and the camber of the steel spring have to be determined for each type of rail.
Schnitt C-D

Fig. 22. — Electric rail bond (for alternating-current). Design : Bavarian State Railway.

Explanation of the German term : Schnitt = Section.

On the Hamburg-Altona line, there are used rail bonds consisting of two copper strips, each having a cross-section of 25 square millimetres (49,340 circular mils), which are secured in the web of the rails by divided copper plugs and steel wedges. More recently, the copper strips have been riveted between two pieces of flat iron bar which are fitted with riveted eyes, and fastened to the rails by the fish-bolts. This prevents their theft, and then the same bonds can be used over again when the rails are renewed. In order to meet the same requirements and in order to eliminate the disadvantages which the bottom bonds of American pattern have, the Bavarian State Railway designed in 1907 the bond shown in figure 22. The contact is to be effected by friction; the bond is pressed by a steel plate which is riveted on, against

the copper plugs riveted into the web of the rail. These bonds can easily be taken out and put in again by the permaneut-way men when the track is being repaired. No experience is as yet available.

On the Hamburg-Altona suburban line, the track is connected at about every kilometre (0·62 mile) with the underground water, by means of earth plates.

Influence on the weak-current conductors.

The important question of how the influence of alternating current conductors on the weak-current conductors (operation of signals, telegraphs, telephones) can best be removed, has not yet received a general solution on the railways operated in Germany.

On the suburban line Berlin-Grosslichterfelde, operated by continuous-current, all the weak-current conductors have special return conductors. On the neighbouring Military Railway, in the electric-bell installations, which had grounded circuits, disturbances arose automatically, so that return conductors had also to be provided in this case.

On the Hamburg-Altona suburban line, operated by 25-cycle alternating-current, the telephone conductors and cables are placed as far as possible from the strong-current conductors. In spite of this, noises sufficiently loud to prevent communication were produced on one section. The noises were only removed by placing the telephones which originally had been placed in series in parallel.

In the block, bell and Morse apparatus of the main railway line running parallel with the electrically operated suburban line, disturbances still sometimes occurred after the return conductors had been put in. They were removed by transferring the earth plates on the main line 2 and 3 kilometres (1·2 to 1·9 miles) outside the influence of the electric suburban line and continuing the return conductors to the earth plates. In addition the common batteries at a given place were replaced by one separate battery for each instrument.

In future cases, where electric operation is going to be applied on a much larger scale and with a considerably-greater effect on main-line operation, it will be possible to receive very valuable help from the extensive and successful investigations carried out by the administration of the Swiss post and railways and the Oerlikon Works conjointly with the Siemens-Schuckert Works. We may refer our readers to the very valuable paper by Mr. Behn-Eschenburg (1).

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(1) See *Elektrische Kraftbetriebe und Bahnen*, 1908, parts 28 to 31; compare also Studer, "Traktion-Seebach-Wettingen", in the *Schweizerische Bauzeitung*, Vol. li, parts 15 to 20; Dahlander, "Versuche mit elektrischen Betrieb auf Swedischen Staatseisenbahnen", and Schrottke, "Einfluss der Hochspannungsleitungen auf die Betriebs-Fernsprech-Leitungen", in the *Electrotechnische Zeitung*, 1907, parts 28 and 29.

These investigations have shown that the disturbances can be removed without having to lay underground cables for the weak-current conductors. That is of considerable importance, as otherwise the cost of the electric operation of main railways would be very materially increased.

The following have been found to be effective :

The use of high-tension porcelain insulators for the weak-current conductors in order to prevent disturbance by the passage of currents;

The crossing of the two wires of each loop to prevent disturbance by electro-dynamic induction;

The introduction of discharging coils between the poles, with centre earthed, in order to prevent disturbance by electro-static induction.

The disturbance by higher vibrations, which issue from the generators and motors, is according to the results obtained in the Swiss investigations prevented by means which avoid an alteration in the magnetic resistance during a revolution. As such are mentioned : .

Slanting pole edges and slots. To have the slots quite closed, as has been recommended, might result in a difficult maintenance of the motor windings. Partly-closed slots, which facilitate the winding, will probably suffice.

The magnitude of the disturbances will probably also be favourably affected by the small periodicity.

VII

Electric locomotives.

Apart from motor-car passenger traffic, which presents the well-known advantages of a quick and frequent service, the electric operation on main railways will have as its chief objective the long-distance passenger and express traffic, and the heavy goods traffic, which will have to be operated as it is now by steam. Consequently, besides motor cars, the design of which presents nothing particularly new, it will be necessary to build locomotives for heavy goods trains and express trains.

The first designs of electric locomotives started with quick-running electro-motors and gear-wheel transmission.

Oranienburg gear-wheel locomotive. — As representative of this system of locomotive with alternating-current motors, the goods-train locomotive of the Prussian State Railway running on the Oranienburg experimental line presents special interest, on account of its simplicity of construction. Its design is shown in

figure 23; a detailed description of it is given in the *Electrotechnische Zeitschrift*, 1908, part. 17. Three Winter-Eichberg motors, each with a continuous output of 250 horse-power, each drive one axle, the ratio of gearing being 1 : 4·21; a fourth motor, to drive the fourth axle, can still be added.

Ease in running round curves is obtained by the division of the locomotive into two sections, with two axles each, closely coupled up.

The locomotive develops a continuous tractive effort of 6,480 kilograms at 31.3 kilometres (14,285 lb. at 19·4 miles) per hour, and a maximum tractive effort of 13,500 kilograms (29,760 lb.). Its maximum speed is 50 kilometres (31 miles) per hour.

The locomotive has been in use since 1907; up to 615 kilometres (382 miles) are run per day of 20 hours (1).

The Oranienburg experiments show very clearly how efficient the electric single-phase motor is and how great an amount of work the electric vehicles can do.

Other designs. — Although spur gearing can be used in the case of goods locomotives owing to the low speed, yet the attention of railway engineers was devoted, not only in the case of goods-train locomotives, but also especially in that of passenger and express locomotives, to the replacement of the spur gear by more suitable transmissions; attention is drawn to this in the Bavarian memoir, appendix, page 12.

The simplest would be to transmit the rotary movement of the electro-motor to the locomotive wheels by having the motors on the driving axles. But such " axle motors " have serious disadvantages. Owing to the low position of the motors between the wheels and the frame, the size of the moter is limited and consequently also its power; then also owing to the great weight of the motors, which it is difficult to support on springs properly, and owing to the lowness of the centre of gravity, the track is subjected to stresses which may become dangerous.

If the locomotive is to run smoothly and safely at high speeds and over sections where there are many curves, its centre of gravity must be as high as possible and the weight of the masses, not carried on springs, must be as low as possible.

These conditions cannot be satisfied except by removing the motors from the axles and supporting them on the frame; the only masses then not supported on springs are the wheels and the axles. The bogies will then also fulfil their proper function, that of producing easy running. If the motors are built into the bogies, the bogie frames lose some of their movability, even if they are equipped with check springs.

Coupling-rod transmission. — The design of locomotive which perhaps best satisfies the condition of easy running, is one with coupling-rod transmission (2).

(1) See *Zeitung des Vereins deutscher Eisenbahnverwaltungen*, 1909, p. 651.

(2) See paper by Wittefeld, in *Glasers Annalen*, 1902, p. 86.

Advantages of coupling-rod transmission. — Coupling-rod transmission presents several advantages from the constructive point of view.

The motor can be entirely removed from the space between the wheels and consequently be made larger and more powerful. This is important in the case of an alternating-current motor, as it requires, together with its commutators, wider room than a rotary-current motor, the slip-rings of which can be outside.

This cheapens and simplifies the electric equipment, as fewer, but stronger motors can be used. Manufacturers were accordingly induced by the railway administrations to construct, not only small motors more suited to motor cars, but also large motors for locomotives, with a correspondingly-smaller number of revolutions, so that the whole work of the locomotive could be done by two motors (1).

As a single axle cannot utilize the power of such a large motor, as the axle-load is limited, several axles must be coupled up. On lines where there are many gradients, it is a great advantage to have as many driving axles as possible; for taking the heavy train-loads now usual into consideration, time in the case of an express service can only chiefly be saved by increased speed on ascending gradients. But this requires a great tractive effort.

Another advantage of having the motors placed high is the great accessibility of the motor; it is easily fitted in and easily taken out for maintenance purposes. Then the motor also does not require to be wholly enclosed; it can cool automatically and no special cooling is necessary. This self-cooling which results from this position is of importance in the case of alternating-current motors, as their constant losses are greater than those of continuous-current motors, and consequently more heating results. Self-cooling only should be used; cooling by electrically-operated air-compressors is too uncertain.

Thus coupling-rod transmission makes a very simple and powerful construction of the locomotives possible; it is therefore also of much importance from the point of view of cost and of the economy of electric locomotives as compared with steam locomotives.

Coupling Frame. — Coupling-rod transmissions have developed in two different directions.

Leaving the earlier attempts out of consideration, such a transmission was first introduced in combination with a stiff coupling frame by Kando (German State patent, No. 148987) on the locomotives of the Italian State Railway.

The coupling frame is a very ingenious device, which makes it possible to make the connection between the motor and the driving axles without introducing another transmitting member, with frictional loss. However, the design of these coupling frames still makes it necessary for the motors to be placed comparatively low relatively to the locomotive frame.

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(1) See *Bavarian memoir*, appendix, p. 12.

In Germany, the following design was accordingly worked out :

Coupling-rods and dummy axles. — A dummy axle is placed between the trailing axle and driving axle at each end of the locomotive.

This dummy axle is at the same height as the driving axles and placed in the frame; it is connected with the axles proper by horizontal and with the motors by vertical or slanting coupling rods (see figs. 24 to 31).

Any injurious reactions on the crank drive are avoided in this way quite as much as by using the Kando coupling-frame.

As it is possible, by shortening or lengthening the coupling-rods between the motor and the dummy axle, to locate the motor wherever desired, the dummy-axle system has the advantage over the coupling-frame system, that the centre of gravity can be placed sufficiently high to ensure smooth running on curves and at high speeds.

Electric locomotives of greater power and suitable speed can be built on this system, not only for express trains but also for heavy passenger and goods trains (1).

The disadvantage of the dummy axle is that an additional rotating member is introduced, producing additional friction.

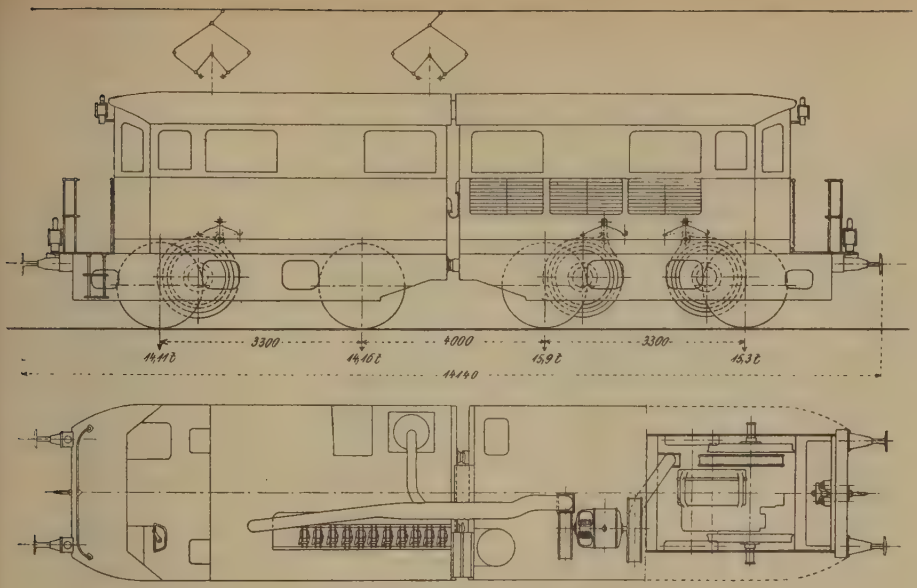
Having considered the general principles affecting the design of these locomotives, we will give a short description of the chief designs of alternating-current locomotives with coupling-rod transmission and dummy axles. We include several machines intended for other countries (Switzerland and France), because they are being constructed in German works. All the locomotives we are considering are equipped with carrying wheels, for the sake of smooth running.

Now if the principle is true that safe running round curves at comparatively high speeds can only be obtained by carrying wheels having a diameter not exceeding 1,000 millimetres (3 ft. 3 $^3/_8$ in.), then the extra weight of the alternating-current locomotive, through the presence of the transformer, as compared with the continuous-current and the rotary-current locomotives, is no disadvantage in the case of passenger and express locomotives having driving wheels with diameters of more than 1,000 millimetres (3 ft. 3 $^3/_8$ in.). It is also no disadvantage in the case of goods locomotives, as it is desirable for these to have more driving axles. A disadvantage only arises if a disproportionately-large weight would make it necessary to have a greater number of axles than would suit the service (2).

$^4/_6$ coupled locomotive with short coupling. — Figure 24 represents the $^4/_6$ coupled alternating-current locomotive of the pattern (1-B-0) + (0-B-1). This locomotive is at present being built by the *Allgemeine Elektrizitäts-Gesellschaft* and the Krauss

(1) As regards the limits of coupling-rod transmissions on goods trains locomotives, taking the diameter of the driving wheels and number of revolutions of the motors into consideration, see *Elektrische Kraftbetriebe und Bahnen*, 1909, p. 425.

(2) See III, note.



3 motors, 250 horse-power each, continuous.

Fig. 23. — Goods-train locomotive of the Prussian State Railway. at work on the Oranienburg experimental line.

Power of motor, 2×800 horse-power.

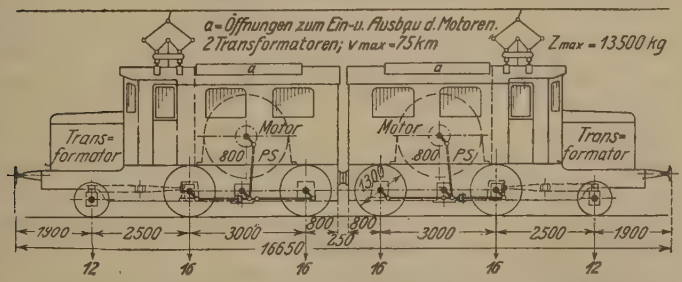


Fig. 24. — Alternating-current locomotive for heavy passenger and goods trains. (Bernese Alpen line, nowbeing built.) Design : *Allgemeine Elektrizitäts-Gesellschaft*, Berlin; *Krauss Locomotive Works*, Munich.

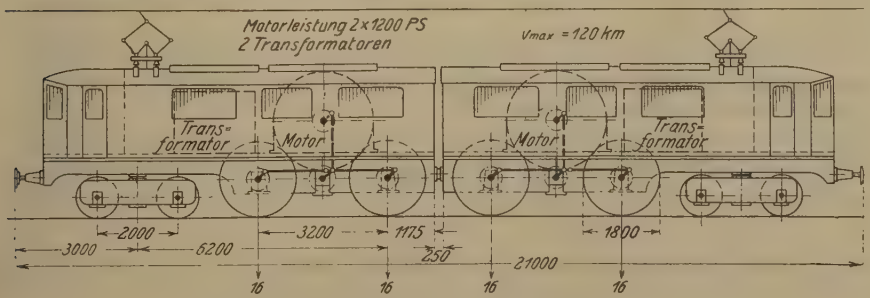


Fig. 25. — Alternating-current locomotive for heavy express trains (project.). Design : *Allgemeine Elektrizitäts-Gesellschaft*, Berlin.

Explanation of German terms : Öffnungen zum Ein- u. Ausbau d. Motoren. 2 Transformatoren = Openings for putting in and taking out the motors. 2 transformers. — Motor = Moteur. — Transformatoren = Transformer. — Motorleistung 2 × 1,200 P. S. = Power of motors, 2 × 1,200 horse-power.

Locomotive Works at Munich and it is intended to haul heavy passenger and goods trains on the Bernese line (Lötschberg tunnel).

In order to have very easy running round curves, the locomotive is divided into two sections closely coupled up, with a common controller. Each section has two driving axles and one carrying axle. The latter is connected with the adjoining driving axles forming a Krauss-Helmholtz bogie; the coupling-rod is articulated so as to allow for lateral displacement of the driving axle. The two transformers are above the carrying axles, and next to them the drivers' cabs, then the compartments containing the motors. In the roof above every motor there is an opening with a movable cover *a*, through which the motors can be lifted out, for maintenance purposes, by means of a travelling crane. There is a gangway through the whole locomotive.

Each of the two Winter-Eichberg motors gives 800 horse-power. The locomotive is to develop an initial tractive effort of 13,500 kilograms (29,760 lb.). Its maximum speed is 75 kilometres (46·6 miles) per hour. The characteristic curves of the motor are shown in figure 35 (1).

4/8 coupled locomotive with short couplings. — Out of this 4/6 coupled locomotive there has been developed, for greater speeds and heavier loads, the 4/8 coupled alternating-current double locomotive shown in figure 25; the designs for this (2-B-0) + (0-B-2) locomotive have been worked on tby the *Allgemeine Elektrizitäts-Gesellschaft*; it is intended for heavy express trains. In order to improve the running and to carry the heavier weights (corresponding to the greater power), the single axle of each section of the locomotive is replaced by a bogie. Then also the two transformers are shifted backwards and the cabs are behind the front faces. The advantage so obtained is that the driver can keep a better look-out, and then also there is considerably more room, under one roof, in which all the machines can be conveniently and accessibly placed.

A further advantage of this arrangement is that the locomotive and the train can have a vestibuled connexion, so that it is easy to pass from one to the other while the train is running; this also reduces the air resistance. Each of the two motors is to give 1,200 horse-power, and the maximum speed is to be 120 kilometres (74·6 miles) per hour.

One advantage of this coupled design, in addition to very easy running round curves, is that half the locomotive can still be used separately, if both sections are equipped with buffing and coupling gear.

In the case of suburban traffic, these halves can also be used instead of motor-cars at the two ends of a train, for corresponding power, so that such a train, like a motor-car train, does not require to be turned at the terminus stations. In this

(1) As regards the characteristic curves and the design of Eichberg motors, see *Zeitschrift des Vereins deutscher Ingenieure*, 1908, p. 1145.

way, the electric equipment and the passenger carriages are kept perfectly separate.

2 × 2/4 coupled double locomotive of the Prussian State Railway. — The Prussian State Railway intends (1) to build 2/4 coupled passenger and express locomotives for use on the Magdeburg-Leipzig-Halle section, of the 2-B-0 pattern; these locomotives can be used in case of heavy loads as double units (2-B-0) + (0-B-2). As figure 26 shows, the motors and transformers are to stand uncovered on the frame.

The motor, which is to give 1,000 horse-power continuously, drives the dummy axle by means of a vertical coupling rod.

If the locomotive is to be used as a half unit, it must be turned at the terminus station so that the bogie is leading.

Locomotive with continuous frame. — Besides this design of a double locomotive with short or ordinary coupling, a design has also been worked out in which both motors are carried on one continuous frame.

3/5 coupled locomotive with continuous frame. — Such a 3/5 locomotive of the design 1-C-1 is shown in figure 27. It is at present being built for the French Southern Railway by the *Allgemeine Elektrizitäts-Gesellschaft* and the Henschel Locomotive Works of Cassel.

It is intended to haul heavy passenger and goods trains, and has three driving axles and two carrying axles. The axle-load is very great; it amounts to 18 tons for the driving axles.

The carrying axles have radial play, while the driving axles have none, except the middle one, which has a little lateral play, to facilitate running round curves.

The locomotive has two motors of 800 horse-power each, and its maximum speed is 75 kilometres (46·6 miles) per hour. Its construction is wholly symmetrical. In this case, there is only one transformer for the two motors, whereas there are two transformers in the designs shown in figures 24 and 25; this transformer is in the middle between the motors. A rectangular box is erected over the whole frame; the drivers' cabs are at its ends. This arrangement has the same advantage as that shown in figure 25.

3/7 coupled locomotive with continuous frame of the Allgemeine Elektrizitäts-Gesellschaft. — Out of this 3/5 coupled locomotive there has been developed, for very great speeds and very heavy loads, the 3/7 express locomotive designed by the *Allgemeine Elektrizitäts-Gesellschaft*; it is of the 2-C-2 type and is shown in figure 28. The two motors are each of 1,200 horse-power. The maximum speed is 120 kilometres (74·6 miles) per hour. In order to attain good running round curves, bogies with lateral play and check springs are used instead of carrying axles.

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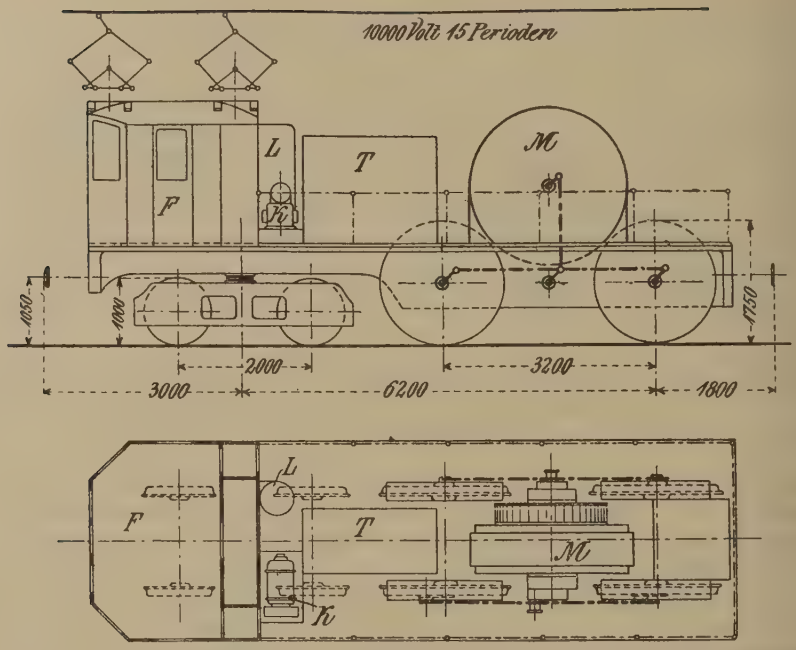
(1) See *Elektrische Kraftbetriebe und Bahnen*, 1909, p. 313.



F = Drivers' cab; K = Compressor; M = Alternating-current motor, 1,000 horse-power; L = Air reservoir; T = Transformer.

Fig. 26. — $^2/_4$ coupled passenger and express locomotive of the Prussian-Hessian State Railways (project). See *Elektrische Kraftbetriebe und Bahnen*, 1909, part 16.

Explanation of German terms : 10 000 Volt, 15 Perioden = 10,000 volts, 15 cycles.

The location of all the heavy masses in the middle of the vehicle (figs. 27 and 28) will have a very great influence on the smoothness of the running, as the polar moment of inertia about the vertical line through the centre of gravity of the locomotive is comparatively small and the distance of the bogie wheels from the bogie centre is very great.

In other respects, this locomotive presents the same advantages as those previously mentioned.

$^3/_7$ coupled locomotive with continuous frame of the Siemens-Schuckert Works and Maffei. — Another design of locomotive has been worked out by the Siemens-Schuckert Works and the Maffei Locomotive Works of Munich conjointly; it is a $^3/_7$ express locomotive of the 2-C-2 type and is shown in figure 29.

The two motors of 1,200 horse-power each are here placed above the bogies, just like the cylinders of the more ecent steam locomotives. The transformers are next

to the motors. The drivers' cab is in the middle. Transformers and motors are protected by a covering. In this design, the motor is quite beyond the driving wheels and consequently not confined to the space left available between them.

In order to enable the motors to be constructed of ample width and have good bearings, the frame plates above the bogie are cut away and the frame is extended by a trough consisting of a steel casting. This trough also helps to stiffen the frame.

This locomotive is to develop a speed of 120 kilometres (74·6 miles) per hour; it is built perfectly symmetrically and the loads are uniformly distributed on the frame.

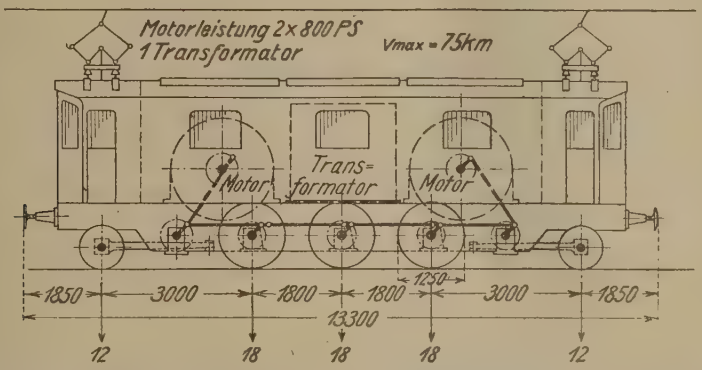


Fig. 27. — Alternating-current locomotive for heavy passenger and goods trains. (French Southern Railway : now being built.) Design : *Allgemeine Elektrizitäts-Gesellschaft,* Berlin.

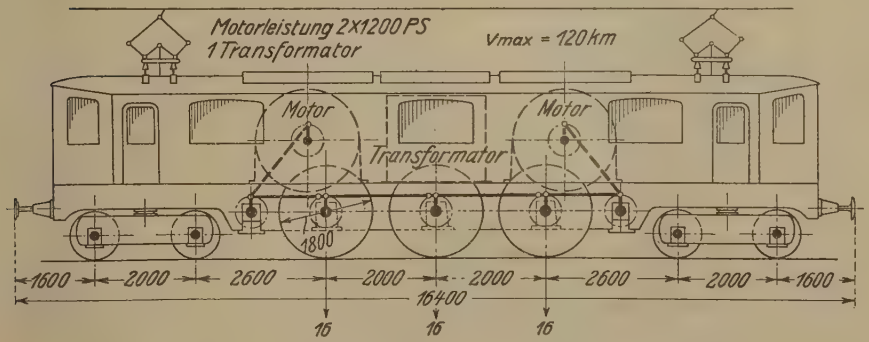


Fig. 28. — Alternating-current locomotive for heavy goods trains (project). Design : *Allgemeine Elektrizitäts-Gesellschaft,* Berlin.

Explanation of German terms : Motorleistung, 2 × 800 PS. 1 Transformator = Power of motors, 2 × 800 horse-power. 1 transformer. — Transformator = Transformer. — Motorleistung 2 × 1 200 PS. = Power of motor, 2 × 1,200 horse-power.

100,000 volts, 15 cycles.

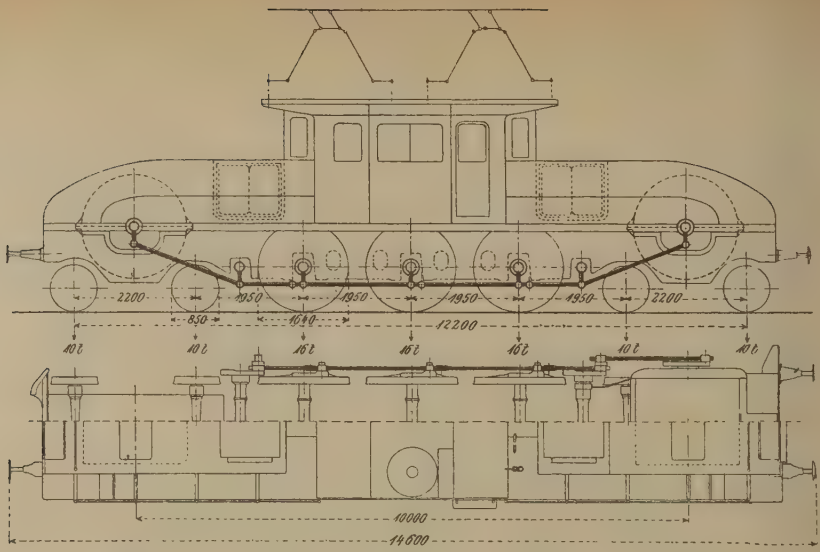


Fig. 29. — $^3/_7$ coupled express locomotive for alternating-current (project).
Design : *Siemens-Schuckert Works*, Berlin; *J. A. Maffei*, Munich.

Power of motor, 2 × 1,200 horse-power. 2 Transformers v max. = 120 km. (74·5 miles).

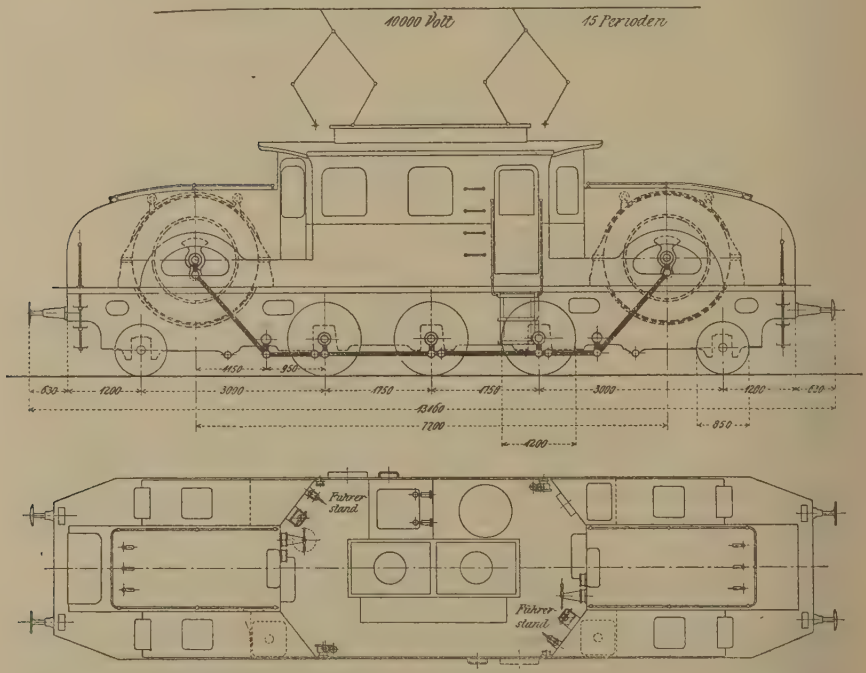


Fig. 30. — Alternating-current locomotive for the Baden-Wiesental line; now being built by the *Siemens-Schuckert Works*, of Berlin, and the *J. A. Maffei* Locomotive Works, of Munich.

Power of motors, 2 × 475 horse-power. Transformer with potential equalizer.

Explanation of German terms : 10 000 Volts = 10,000 volts. — 15 Perioden = 15 cycles.
Führerstand = Position of driver.

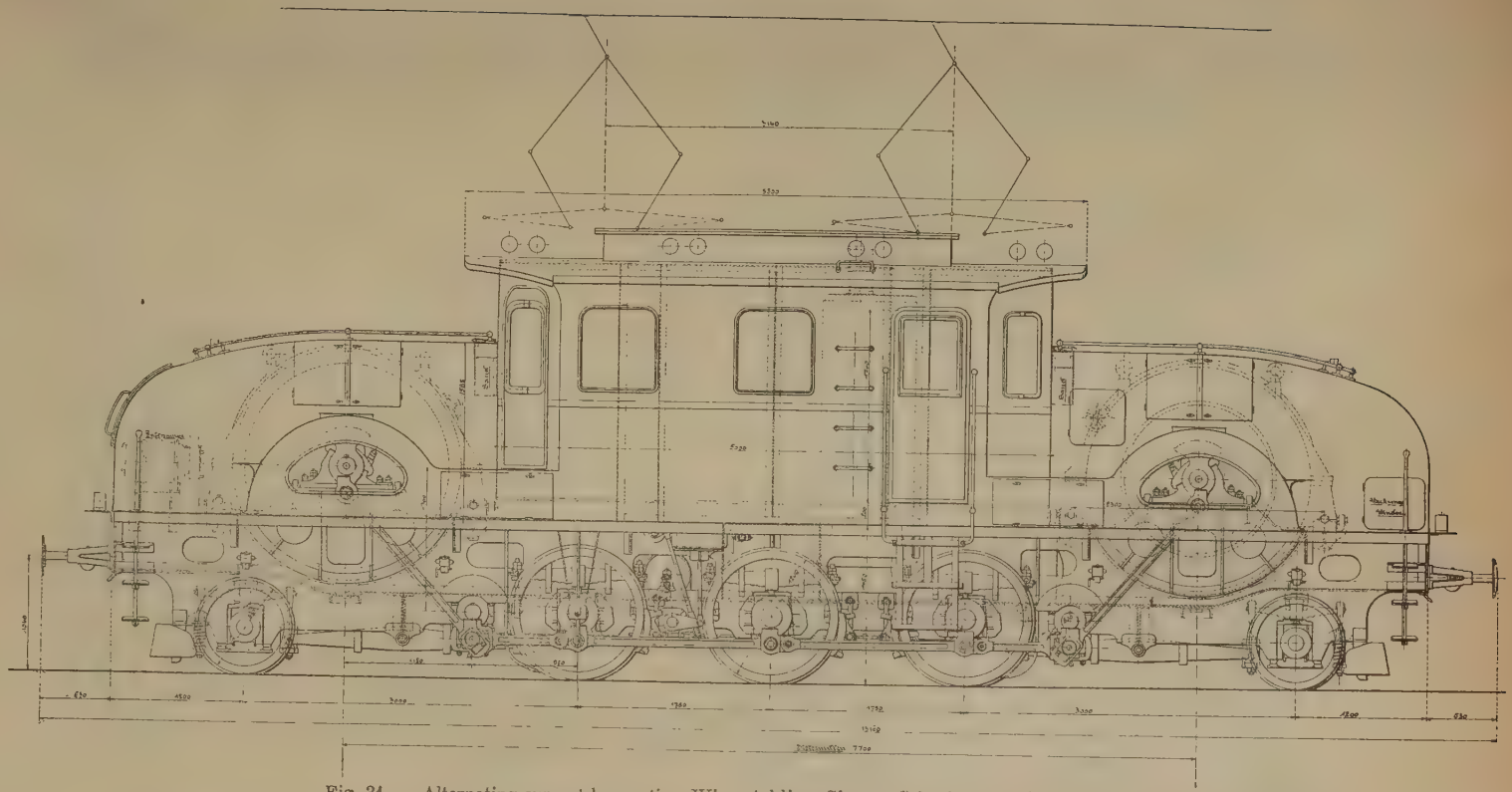


Fig. 31. — Alternating-current locomotive, Wiesental line; Siemens-Schuckert, Maffei (now being built).

Explanation of German terms : Motormitten = Centres of motors. — Pumpe = Air pump. — Sand = Sand. — Werkzeuge und Winden = Tools and jacks.

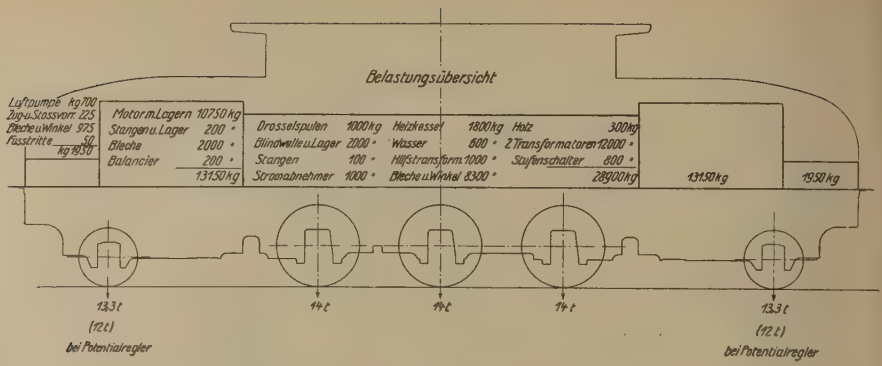


Fig. 32. — Electric continuous-current locomotive for the Wiesental line.
Design : Siemens-Shuckert Works, Berlin ; J. A. Maffei, Munich.

Suspended weight	59,100 kilograms	(130,290 lb.).
Dead weight	9,500 —	(20,940 —).
Total weight.	68,600 kilograms	(151,230 lb.).

Explanation of German terms : Belastungsübersicht = Distribution of load. — Bei Potentialregler = With potential equalizer. — Luftpumpe = Air pump. — Zug- u. Stossvorr. = Draft gear and buffing gear. — Bleche u. Winkel = Plates and angles. — Fusstritte = Footboards. — Motor m. Lagern = Motor and bearings — Stangen u. Lager = Rods and bearings. — Bleche = Plates. — Balancier = Balance weight. — Drosselspulen = Choking coils. — Blindwelle u. Lager = Dummy axle and bearings. — Stangen = Rods. — Stromabnehmen = Current collectors. — Heizkessel = Boiler. — Wasser = Water. — Hilfstransform = Auxiliary transformer- — Bleche u. Winkel = Plates and angles. — Holz = Wood. — 2 Transformatoren = 2 transformers. — Stufenschalter = Step switch.

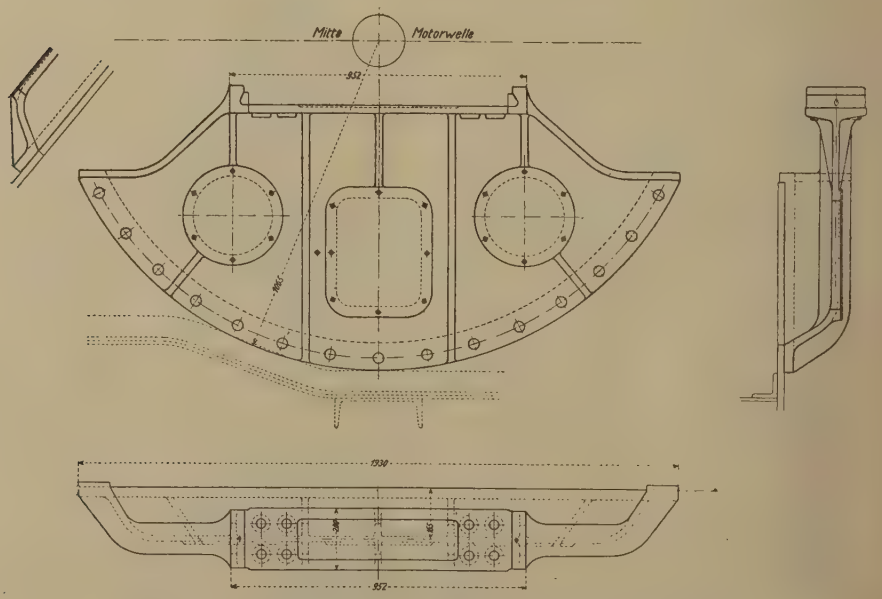


Fig. 33. — Support of bearings of Wiesental electric locomotive.

Explanation of German terms : Mitte Motorwelle = Centre of the motor axle.

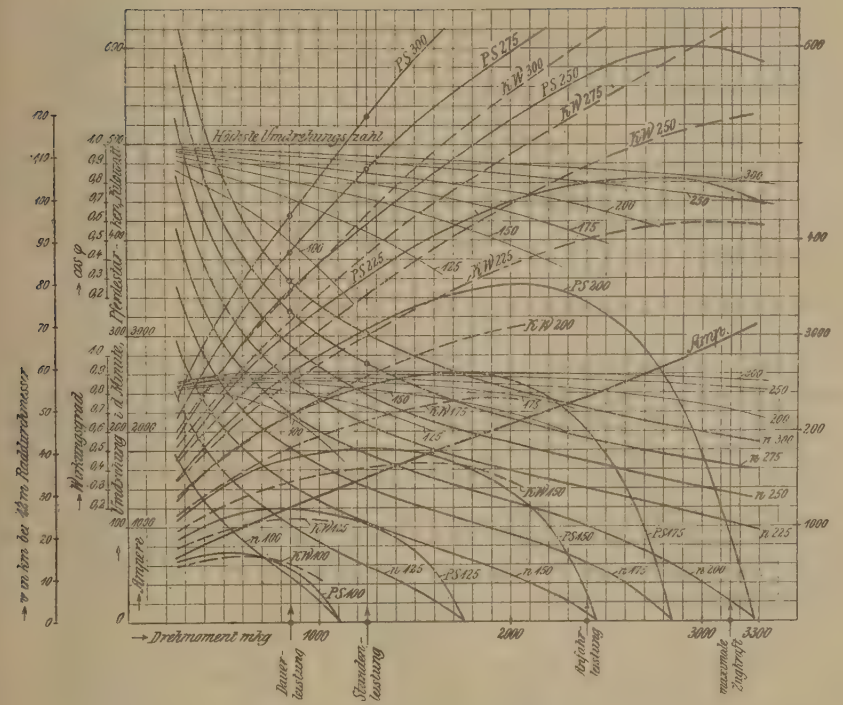


Fig. 34. — Characteristic curves of the alternating-current railway motor W. B. M. 1700. 15 cycles. Siemens-Schuckert Works, Wiesental line.

Tractive effort of a locomotive :

Continuous . . $2 \times \frac{850}{0.6}$ ~ 2,950 kilog. (6,280 lb.).

For an hour . . $2 \times \frac{1,250}{0.6}$ = 4,100 — (9,040 —).

Initial. . . . $2 \times \frac{2,400}{0.6}$ = 8 000 — (17,640 —).

Maximum . . $2 \times \frac{3,150}{0.6}$ = 10,500 — (23,150 —).

Power of a moteur at	Continuous. 850 Meterkilogram.			For one hour. 1,250 Meterkilog.		
	n	*v*	PS	*n*	*v*	PS
275 volts	325	74	390	270	61	475
300 volts	358	81	425	302	68	528

Explanation of German terms : v in km. bei 1.2 m. Raddurchmesser = *v* in kilometres per hour with a wheel diameter of 1·2 metres (3 ft. 11 1/4 in.) — Wirkungsgrad = Efficiency. — Umdrehungen in der Minute = Revolutions per minute. — Pferdestärken Kilowatt = Horse-power kilowatts. — Dauerleistung = Continuous power. — Stundenleistung = Power for one hour. — Anfahrleistung = Initial power. — Maximale Zugkraft = Maximum tractive effort. — Drehmoment mkg = Twisting moment.

The masses are however comparatively far from the vertical line passing through the centre of gravity. But the smoothness of running will be improved by the more horizontal position of the coupling rods from the dummy axle.

*

It is more difficult in this case to pass from the locomotive to the train while running, than in that of the design with a body like that of a carriage, shown in figures 24 to 28.

$^{3}/_{5}$ coupled locomotive with continuous frame. — Out of this locomotive there has been developed for heavy pasenger and goods traffic, the $^{3}/_{5}$ coupled alternating-current locomotive of the 1-C-1 type shown in figure 30. This is at present being built by the Siemens-Schuckert Works and the Maffei Locomotive Works for the Wiesental line.

Wiesental Line Locomotive. — Figure 31 shows an external view of this locomotive.

Owing to the low maximum speed, each bogie is replaced by one carrying axle, which is of the Adams type with inclined check surfaces and has a lateral play of 40 millimètres ($1\ ^{9}/_{16}$ inch) on each side. The motors are placed nearer the middle and the transformers are in the middle of the drivers' compartment. The distribution of the loads on the frame and the wheel-loads are shown in figure 32.

The trough-shaped longitudinal frame plate provided for the bearing is a steel casting of the shape shown in figure 33. It is fixed to the framework as a dovetail. The bearings of the motor are located on this trough. The motor armature can be adjusted in its proper position by packing pieces of thin plate.

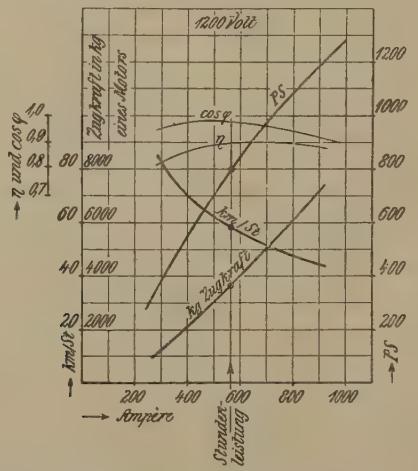


Fig. 35. — Characteristic curves of the alternating-current motor WE 151. Allgemeine Elektrizitäts-Gesellschaft. Bernese Alps line. 15 cycles.

Explanation of German terms : η und cos φ = η and cos φ. — Kmt St = Kilometres per hour. — Zugkraft in kg eines Motors = Tractive effort, in kilograms, of one motor. — 1 200 volt = 1,200 volts. — Kg. Zugkraft = Tractive effort. — Ampère = Amperes. — Stundenleistung = Power for one hour. — PS = Horse power.

Each of the motors gives 390 horse-power continuously and can give 475 horse-power for one hour. The locomotive thus develops a continuous tractive effort of 3,000 kilograms (6,610 lb.) at a speed of 74 kilometres (46 miles) per hour; and a tractive effort for one hour of 4,000 kilograms (8,820 lb.) at a speed of 61 kilometres (37·9 miles) per hour; the initial tractive effort is 8,000 kilogrammes (17,640 lb.). The characteristic curves of the motor are shown in figure 34 (speed, tractive effort, strength of current, consumption of energy, horse-power developed for the different tensions, as obtained by the controller).

The motors are series wound with armature with equipotential winding and auxiliary excitation.

The external diameter of the motors is 2,180 millimetres (7 ft. 1 $^{13}/_{16}$ in) and that of the armature is 1,500 millimetres (4 ft. 11 in.). The commutator has an external diameter of 1,400 millimetres (4 ft. 7 $^{1}/_{8}$ in. and a width of 300 millimetres (11 $^{13}/_{16}$ inches); the division is 6 millimetres ($^{15}/_{64}$ inch). The carbon brushes have a cross-section of 12·5 × 60 millimetres ($^{31}/_{64}$ × 2 $^{3}/_{8}$ inches) and are 50 millimetres (1 $^{31}/_{32}$ inches) high.

The air space between the armature and the stator is 2·5 millimetres ($^{3}/_{32}$ inch).

The motors are readily accessible; a motor can also be easily lifted out.

The transformers have a ratio of 10,000 : 300.

The machines are not going to be fitted with the ordinary controller, but with a fine stop adjustment and potential equalizer.

Above the two drivers' cabs there are two current collectors. These consist of shears which can be raised and lowered by hand or by compressed air. They carry a light bow which can move freeiy, with an aluminium sliding contact.

The high-tension gear is enclosed in a special compartment.

The locomotive carries a steam boiler for warming the passenger trains.

Ten locomotives of this kind are being built for the Wiesental line.

The first locomotive is to be ready by the end of the year and is to be tested on the Murnau-Oberammergau line.

Nothing is yet known about the design of the two other locomotives which are going to be supplied to the Wiesental line by Messrs. Brown, Boveri & Co.

The designs for the locomotives for the Bavarian Salzburg-Reichenhall-Berchtesgaden line are at present being worked out.

[621. 33]

REPORT N° 3

(Austria and Hungary)

By Arthur HRUSCHKA, Dr. Tech.,

K. K. BAURAT AND REPORTER OF THE DEPARTMENT COMMISSIONED BY THE AUSTRIAN RAILWAY ADMINISTRATION FOR STUDYING AND PREPARING THE INTRODUCTION OF ELECTRIC TRACTION ON THE STATE RAILWAYS.

CONTENTS.

Introduction.

I. — *Electric full-gauge railways in actual operation* (see also Appendix I).

II. — *Electric full-gauge railways under construction* (see also Appendix II).

III. — *Electric full-gauge railways planned and under consideration* (see also Appendix III).

a) Investigations by the Austrian State Railways : general considerations; investigations of detail; service requirements.

b) Investigations by the Hungarian State Railways.

c) Investigations by the Southern Railway Company.

d) Other investigations and plans by the following railways : Vienna-Pozsony, Innsbruck-Mittenwald, Niederösterreichische Landesbahnen, Nyiregyháza-Dombrád, Mezőhegyes-Kovácsháza.

Summary.

Appendix I contains descriptions of the full-gauge railways in operation (*viz.* Bludenz-Schruns, Tabor-Bechyn, Innsbruck-Fulpmes, Vienna-Baden, Bruneck-Sand in the Tyrol, Neumarkt-Kallham - Waizenkirchen and Niederspaching-Peuerbach, Brünn tramways [goods locomotives], Triente-Malè, Nyiregyháza-Dombrád).

Appendix II countains descriptions of the full-gauge railways under construction (*viz.* Vácz-Gödöllő, St. Pölten-Mariazell-Gusswerk).

Appendix III countains particulars of the plans for the following full-gauge railways : Trieste-Opcina, Prague-Nusle-Smichow, Znaim-Raabs.

Appendix IV is the enquiry form relating to Question VIII.

*

INTRODUCTION..

Since the reports on " Electric Traction " to the 5th, 6th and 7th sessions of the Railway Congress (1), this new problem has been surveyed and considered by railway managements from a very much broader point of view. While the first electric railways originated in the demand for certain technical advantages (such as adaptability to varying conditions of service, increase in speed, smokelessness, suitability for running small trains, possibility of increasing the traffic, etc.), it was recognised in the course of development of the electric system that the above advantages could be combined with commercial advantages, especially when water power could be drawn upon to supply the necessary power. The decision to adopt electric traction or otherwise was largely, if not mainly, dependent on the financial outlook, *i. e.* whether the new system was likely to improve the financial results, or at least not to impair them as compared with the older system of working. A third point of view related to possible political and military advantages, due to independence of the supply of coal and increase in traffic facilities. In view of the enormous amount of capital sunk in railways, it is obvious that the possible commercial advantages ranked first in point of importance. In view of the above, electric railways will in the future be classified in two groups, as follows : those railways which are converted to electric traction to obtain technical or political advantages, even if the financial results are thereby impaired, and those railways which are electrified because such electrification offered an expectation of increase profits.

The financial results of electric traction as compared with steam traction are chiefly dependent on :

a) a sufficiently low price of the current, whether bought or generated in the railway's own power station,

b) a sufficiently heavy traffic (thus making the maximum possible use of the wires),

c) a sufficiently large energy consumption per gross ton-kilometre, owing to steep gradients or high speeds.

With respect to the above considerations, Austria can be divided into two parts separated by the Danube. In the southern part the ample water powers of the Alps and the Dalmatian mountains must be considered as almost the only source of power, for locomotive coal must, as a rule, be brought from long distances and is consequently expensive. Traffic is partly light, partly fairly heavy. Steep gradients are practically the rule and there are many tunnels. In the northern part, on the other hand, the necessary power would have to be produced by coal, crude oil or fuel of low calorific value. The lines in this part, which have light gradients and many level stretches, have for a large part to deal with very heavy traffic.

(1) *Bulletin du Congrès des chemins de fer*, 1895, No. 6; 1900, Nos. 8 and 9; 1904, No. 11 and 1905, Nos. 1, 3 and 4.

These considerations point to the conclusion that the southern part is even at present very suitable for the introduction of electric traction. The large consumption of coal per ton-kilometre, the high prices for coal and the abundance of water power justify the assertion that electrification can be carried out with commercial advantage at the present time, and that even greater advantages may be hoped for in the future. The radius of profitable operation from the coal fields in the northern part (which produce coal of high calorific value) as a centre, ranges from 400 to 800 kilometres, and beyond this towards the south it is frequently necessary to use expensive English coal or else to employ local coal of poor value, not very suitable for locomotive purposes. There are here many lines which might profitably be electrified on technical grounds alone, such as prevention of the smoke nuisance in single-track tunnels on gradients and in curves and the possibility of increasing the traffic. On most of the lines running along mountain ranges, it would be difficult to construct a second track, even if this could be justified on commercial grounds, which is not the case. The construction of crossings on gradients of over 2 per cent would be very expensive.

The conditions in Hungary are in some cases similar, but only on comparatively small portions of the railway network. Steep gradients with numerous tunnels are only met with near the frontiers, where water power is also available. The first electric railway in this country (Vácz-Gödöllő) is, it is true, operated from a power station equipped with heat engines, but this line was chiefly built to cope with an expected increase in traffic to assist in dealing with the traffic to and from Budapest.

The reason why the building of electric full-gauge railways in Austria and Hungary is only now commencing, in spite of the propitious conditions, is that the railway administrations adopted a waiting attitude in view of the rapid advancement of electric traction and of the difficulty in deciding on a definite system for a country with so many different traffic conditions; also, because it was necessary to obtain clearness as to the financial results before embarking on extensive conversions.

These considerations moved the railway administrations to study the problems in detail; the Austrian railway administration was foremost in this respect, but investigations were also carried out by the Hungarian railway administration, by the Southern company and by various smaller railway companies. In all cases, the opinion is that the advanced state of electric traction renders experimental traction on short lines, or with few cars, superfluous, and that a beginning should be made with a sufficiently long line dealing with heavy traffic; indeed, the belief is universal that the best system to adopt with the lowest renewal and maintenance costs can only be properly decided by electrifying long lines possessing the most severe traffic conditions. It may therefore be hoped that — at least on the Austrian State railways — a beginning will shortly be made on a broad basis.

In my report, I have first dealt with the existing lines in Austria and Hungary (which were practically neglected in former Reports to the Congress, and which have

been augmented since the last session by the two important lines Vienna-Baden and Trient-Malè), and have then discussed the lines under construction and, finally, have described some projects. The report is therefore divided into three sections, dealing respectively with railways in operation, under construction and under consideration.

Only three months were at my disposal in which to draw up the report, as I was only asked on the 6 September 1909 to undertake this work. Previous to this, however, detailed enquiry forms (1) were sent by the permanent Commission of the Congress to the following :

Austrian Railway Ministerial Department (for the Austrian State Railways),

Hungarian State Railways,

Austro-Hungarian State Railway Company,

Austrian Nordwestbahn and Südnorddeutsche Verbindungsbahn (the three last-mentioned private railways have since then been incorporated in the Austrian State Railways),

Austrian Southern Railway Company.

Of the above railways, only the Austrian and Hungarian State Railways and the Südbahn have sent in replies to the enquiry forms, and the completion of the present report was only made possible by drawing upon the information available at the investigation department of the Austrian railway Department (to which I had access in my official capacity as reporter) and by obtaining information from a number of other railways, to which enquiry forms were not sent, and from the following electrical firms : " Siemens-Schuckert Werke ", " Allgemeine Elektrizitäts-Gesellschaft ".

I. — Electric full-gauge railways in operation.

The only electric railways in Austria and Hungary at the end of 1909 were secondary and local railways. Seven of these lines, with a total length of 174 kilometres, have a sufficiently heavy service and are of sufficient length to render them comparable, as regards traffic conditions, with main lines. These lines are :

LINE.	Current and voltage.	Length in kilometres.	Gauge in metres.	Opened in.
Tabor Bechyn	D. C. 2 × 700	23·595	1·435	1903
Innsbruck-Fulpmes.	Single phase, 2,500	18·164	1	1904
Bludenz-Schruns	D. C. 500	12·506	1·435	1905
Vienna-Baden	Single phase D. C. 550	28·721	1·435	1907
Bruneck-Sand in the Tyrol. . . .	D. C. 500	15·240	1·435	1908
Neumarkt-Waizenkirchen	D. C. 500	46·290	1·435	1908
Niederspaching-Peuerbach . . .				
Trient-Malè	D. C. 800	59·600	1	1909
		174·116		

(1) The list of questions had been drawn up by Professor D. Gleichmann, reporter for Germany, whose report appeared in the March, 1910, number of the Bulletin of the Railway Congress.

It might also be mentioned that since 1909, several goods locomotives are being used on the full-gauge tramway system of Brünn.

For the sake of completeness the following systems, which are partly extended tramways and partly mountain railways, may be added :

LINE.	Length, in kilometres.	Gauge, in metres.	Opened in
Mödling-Hinterbrühl	4·4	1	1883
Baden-Helenental Baden-Vöslau	10·2	1·435	1894
Bielitz-Zigeunerwald	4·9	1	1895
Brüx-Oberleutensdorf-Johnsdorf	12·9	1	1901
Dorbirn-Lustenau	11·1	1	1902
Brünn local railways	14·5	1·435	1899
Kaltern-St. Anton	2·4	1·435	1903
See-Unterach	3·2	...	1907
Lana-Meran	7·6	1	1906
Bozen-Oberbozen (Rittner mountain railway)	10·9	1	1907
Abbazia-Mattuglie-Lovrana	11·9	1	...
Dermullo-Mendel	24	1	1909
Budapest-Sz. Lörincz	11·5	1·435	...
Budapest-Budafok	8·7	1·435	...
Miskolez-Diósgyör	6·9	1·435	...
Hölak-Trencsénteplicz	5·9	0·76	1909
About. . .	151		

The above table only includes lines operated purely by adhesion between wheels and rails.

Appendix I contains the chief particulars, both technical and commercial, relating to the seven lines mentioned above.

II. — Electric full-gauge railways under construction.

There are at present two lines of a combined length of 141 kilometres (87·6 miles) under construction, and it is possible that they will be running by the time the eight session of the Congress opens.

They are :

Vácz - Rákospalota — Ujpest - Gödöllö, 50 kilometres (31 miles) long, full-gauge secondary railway with comparatively heavy traffic; it is operated by single-phase current at a voltage of 10,000 volts and a frequency of 15 cycles per second.

St. Pölten-Mariazell-Gusswerk, 91 kilometres (50·3 miles) long, gauge 76 centimetres (2 ft. 6 in.) local railway with comparatively heavy trains; it is operated by single-phase current at a pressure of 6,000 volts, and a frequency of 25 cycles per second.

It is interesting to note that the first-mentioned line will be the first railway

in Austria and Hungary to be operated at 10,000 volts single phase and 15 cycles per second, while the second railway is remarkable on account of the fact that the locomotives are exceptionnally powerful (500 horse-power) considering the narrow gauge.

Appendix II contains all the important data relating to the these two lines which are at present available.

III. — Electric full-gauge railways under consideration and planned.

a) Investigations undertaken by the Austrian State Railways.

As already mentioned, the lines to the south of the Danube represent the most favourable portion of the Austrian railways as regards electric traction. They have a total length of 6,000 kilometres (3,730 miles) in round figures, and 4,380 kilometres (2,722 miles) of this total length belong to the state or are worked by the state for the owners. The natural advantages possessed by the districts situated in the alpine regions, induced the Austrian State Railway Department as far back as 1903 and 1904, to ask the most important electric firms in Austria to submit specifications and plans for electrifying the gradients of the Arlberg railway between Landeck and Bludenz and the Karawanken and Wocheiner railways (which were then under construction) as far as Trieste (Klagenfurt-Trieste and Villach-Trieste). The detailed specifications which were submitted differed greatly as to the kind of current, voltage and frequency to be employed, but they nevertheless indicated that considerable economy could be hoped for in electrically-operated moutain railways; this conclusion was also independently arrived at by the Railway Department which worked out a rough estimate for the Schwarzach-St. Veit-Badgastein-Villach line, at that time still under construction.

At the same time, the available water powers, which play such an important part in connection with electric traction, were thoroughly investigated, and this question became one of the most important of the preliminary studies. Water powers exceeding 1,500 horse-power had not only to be found and examined as regards their constancy, but investigations had also to be undertaken as to the possibility, or otherwise, of storing up the water. This done, a selection of suitable water powers had to be made, and the technical difficulties in the way of developing the available energy had to be thoroughly gone into.

In 1906, a branch of the railway department was formed to study the technical and commercial problems relating to the introduction of electric traction on railways. The hydraulic part of the investigations comprised a compilation of all the large sources of water power suitable for traction purposes and the elaboration of general plans for utilising certain heads of water (some 108 such plans were worked out up to the year 1909) and the

working out of 11 schemes in detail of an aggregate capacity of 140,000 horse-power.

As already mentioned, the range of investigations was limited to the state-operated railways to the south of the Danube. This network is under the control of the administrations in Innsbruck, Linz, Vienna, Villach and Trieste and hasa total length of 4,450 kilometres (2,765 miles), of which 3,919 kilometres (2,435 miles) are single track, 3,812 kilometres (2,369 miles) full gauge, 508 kilometres (315 miles) with a gauge of 76 centimetres (2 ft. 6 in.) and 60 kilometres (37·3 miles) with a gauge of 1 metre (3 ft. $3\,^3/_8$ in.). In addition to the general investigations, it was also necessary to draw up detailed plans for certain lines. A selection was made of those lines which appeared most promising for the introduction of electric traction. These selected lines had a total length of 990 kilometres (615 miles) about $^1/_4$ of the total length of the railway network under consideration) and they were submitted to careful examination in detail. Figure 1 is a map of these lines, while figure 2 contains the chief technical data of these lines in graphic form. The names of the railways in question are given on the accompanying table.

The *general investigations* on the whole network of 4,380 kilometres (2,722 miles) covered the following ground :

a) The calculation of the energy required for the whole network, its classification with respect to various lines so as to form a basis for future technical calculations.

b) Investigations as to the conditions which must be fulfilled by the electrical equipment so as to meet the requirements of the various lines, and a critical examination of the alterations in the railway service, track maintenance and accounting in as far as such alterations are due to the conversion to electric service or are desirable for other reasons.

c) General commercial considerations.

d) Compilation and critical examination of all material obtainable from technical publications, books on travel, essays, etc., and dealing with the design, construction and running of electric full-gauge railways in all countries.

The *investigations of details* were chiefly concerned with :

e) Worked-out plans for certain lines (technical reports, calculations of the capital and running costs, comparison between the costs of electric traction and steam traction) which are intended to serve as basis for competitive tenders and

f) the dealing with tenders and the carrying through of the construction of the lines converted to electric traction.

In the course of time, the above investigations will obviously have to be extended to include the standardisation of various technical and commercial particulars, the creation of new standards as may be required by the advancement of electrical science or dictated by the results of our own and foreign railways.

The time has not yet arrived for electrifying any considerable portion of the state railways on the north side of the Danube; the existence of extensive coal fields and crude oil wells having the effect of limiting electric traction to certain

Table of Austrian State Railway Lines for which detail plans for electric traction have been worked out.

RAILWAY LINE.	NAME OF RAILWAY.	Length in kilometres			Maximum gradient per mil.	Average of daily gross tons.		Gauge.
		total.	single track.	double track.				
Innsbruck-Lindau	Arlberg railway with connecting lines.	204·032	190·105	13·927	3·14	1908	6,800	Standard.
Feldkirch-Buchs	...	18·527	18·527	...	1·05	1908	3,450	—
Bregenz-St. Margrethen	...	12·664	12·664	...	0·5	1908	3,700	—
Bozen-Meran	...	31·485	31·485	...	1·00	1908	2,750	—
Meran-Mals	Vinschgau railway.	59·828	59·828	...	2·80	1908	800	—
Mals-Landeck	Reschen railway (under consideration).	88·800	88·800	...	2·50			—
Steinach-Irdning-Attnang-Puchheim	Salzkammergut railway.	107·580	107·580	...	2·50	1908	2,200	—
Schwarzach-St. Veit-Spittal-Millstättersee-Villach S. B.-Rosenbach	Tauern railway with connecting lines.	140·759	93·141	47·618	2·665	eventually.	10,000	—
St. Veit a. d. Glan-Assling-Görz St. B.-Opcina St. B.	Karawanken- and Wocheiner railway with connecting line to Opcina.	189·950	169·702	20·248	2·67	—	12,700	—
Opcina St. B.-Trieste k. k. St. B.	...	15 567	15·567	...	2·71	—	12,700	—
Weizelsdorf-Ferlach	...	5·705	5·705	...	1·40	1908	430	—
Görz S. B.-Haidenschaft	Wippachtal railway.	26·910	26·910	...	1·50	1908	490	—
Herpelje-Kozina-Trieste k. k. St. B.	...	19·590	19·590	...	3·272	1908	1,560	—
Trieste k. k. St. B.-Buje	...	59·410	59·410	...	3·095	1908	300	0·760 m.
Trieste k. k. St. B.-S. Sabba	...	4·749	4·749	...	2·84	1908	1,710	Standard.
Trieste k. k. St. B.-Rgbhf. Barcola	Riva railway.	4·773	4·773	...	1·84	1908	2,450	—
Total	...	990·324	908·531	81·793	...	...	...	...

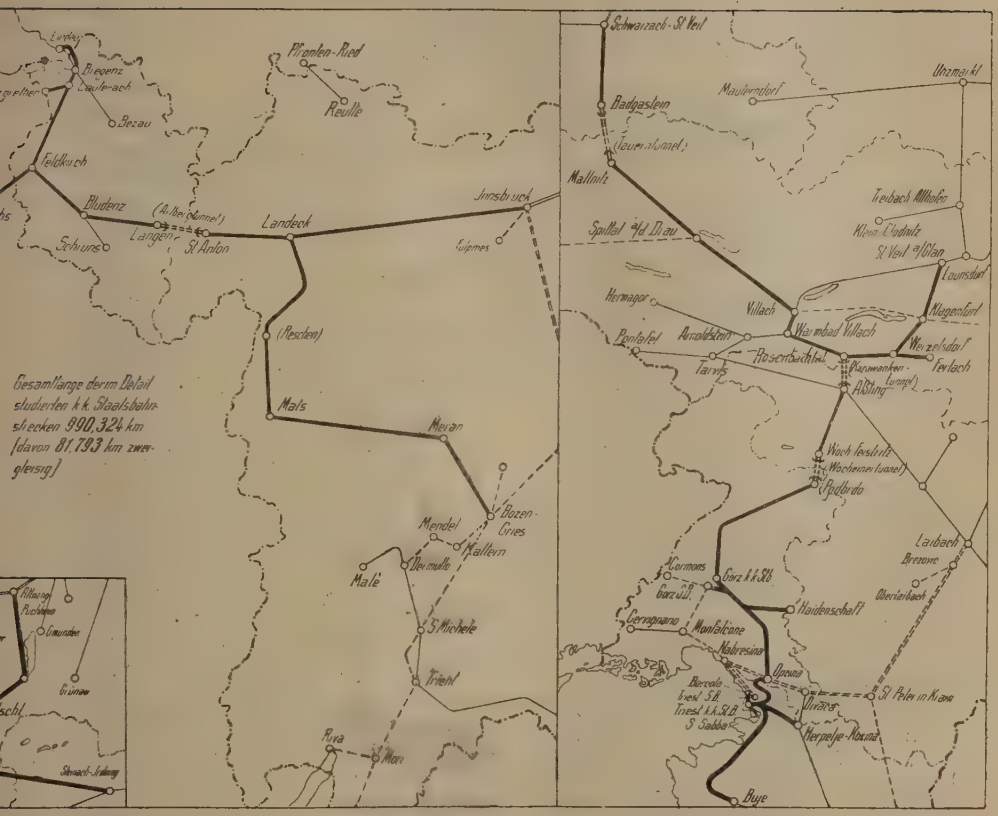


Fig. 1. — Maps of the Austrian State Railway lines for which detailed plans for electric traction have been prepared.

Explanation of German term : Gesamtlänge der im Detail studierten k. k. Staatsbahnstrecken 990.324 km (davon 81.793 km zweigleisig) = Total length 990·324 kilometres (615·370 miles) of which 81·793 kilometres (50·825 miles) are double track.

lines, which are even at the present time clearly indicated.

The investigations on the energy required are so far completed that a full report covering the whole range of studies will shortly appear. This report will not only give the results of the calculations, but will also discuss the special methods adopted for the investigations and the numerical assumptions on which the calculations are based. I hope to be able to submit this report to the Congress.

A plan, fully worked out from the service point of view, is in existence for the Trieste-Opcina line. Similar plans are now being elaborated for the Innsbruck-Lindau line with connecting lines, for the line from St. Veit on the Glan to Trieste,

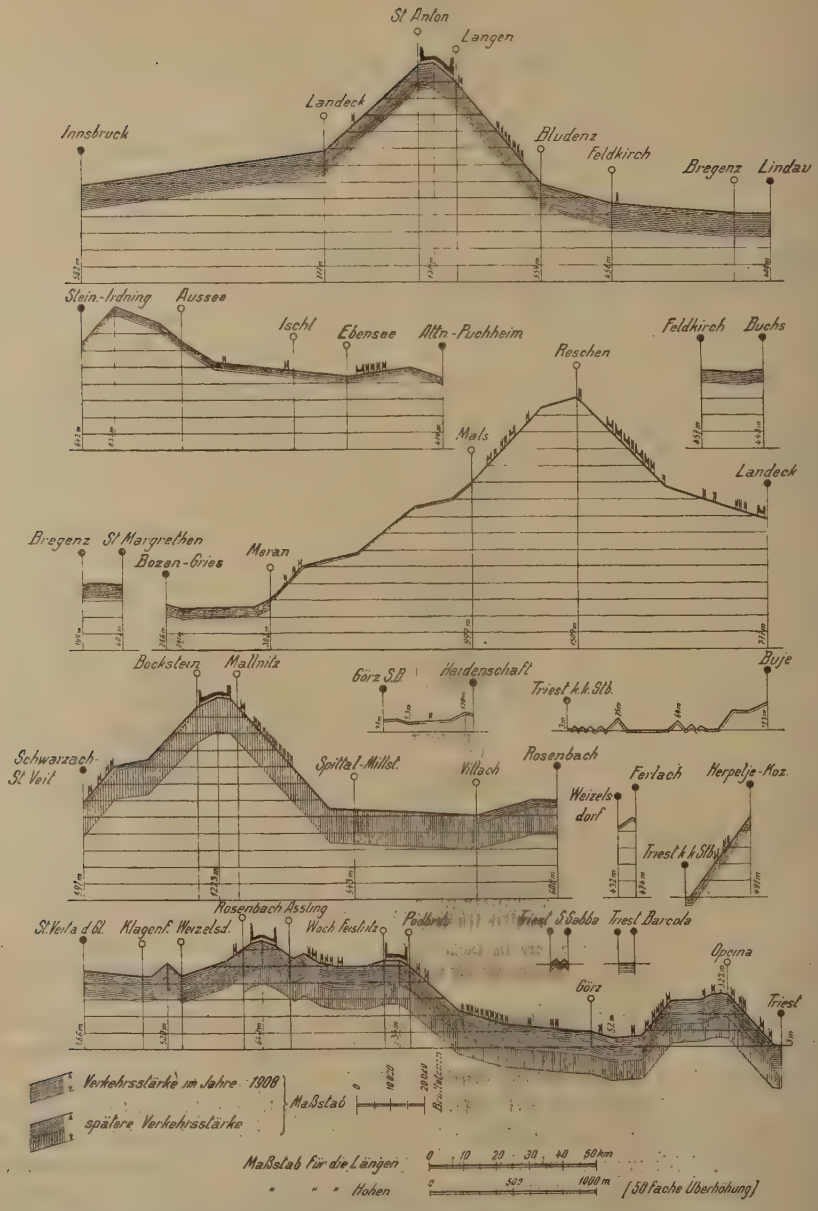


Fig. 2. — Profiles of the Austrian State Railway line for which detailed plans for electric traction have been prepared.

Explanation of German terms: Masstab für die Höhen = Scale for heights. — Masstab für die Längen = Scale for distances. — Spätere Verkehrsstärke = Future traffic. — Verkehrsstärke im Jahre 1908 = Traffic in 1908. — Masstab = Scale. — Bruttotonen = Gross-tons.

for the Bozen-Mals line and for the Stainach-Irdning-Attnang-Puchheim line.

In addition to the lines enumerated in the table, there is the Prague-Nusle line, the only line to the north of the Danube for which plans are being prepared. This line has only moderate gradients, and the chief reason for converting it to electric traction is the wish to do away with the smoke nuisance in the Prague tunnel (1 $^1/_2$ kilometre [0·93 mile] long) and to ease the traffic by eliminating part of the locomotive journeys between Prague and the coal depot at Nusle, on the other side of the tunnel.

In view of the negociations now pending between the State Railway Department and various private corporations for the supply of electric current, I am not at present in a position to discuss the financial side of these lines.

For the sake of completeness, the experiments on electric traction carried out during recent years on the Vienna urban railway may here be mentioned. In 1901 and 1902, experiments were made on the Michelbeuern-Heiligenstadt line with a train equipped by Siemens & Halske. The motors were fed with continuous current at 550 volts, which was picked up from a third rail. The control was of the multiple-unit type. The motors were mounted on the axles. At first shunt motors were used, but these were afterwards replaced by series motors which gave much better results. In the former case, considerable trouble was experienced owing to the loads on the various motors being unequal. In both cases, the weight of the train was considerably increased by employing motors which were directly mounted on the axles.

In the years 1906 and 1907, the firm of Fr. Křižik conducted trials on the Hauptzollamt-Praterstern section of the Vienna connecting line with a continuous-current 3-wire locomotive (2 × 1,500 volts, 2 axles, 29 tons weight when complete for service).

At present, no further experiments are being carried out. Negociations between the parties concerned in the Vienna urban railway (*i. e.* the State, Lower Austria and the Vienna municipality) with regard to electric traction are still pending.

Requirements of the service.

The investigations carried out so far have cleared up to some extent certain questions relating to service conditions and permit certain conclusions to be arrived at. In view of the importance of the subject, however, and until official decisions are available, these conclusions are to a certain degree only personal ones, and the following remarks should therefore be regarded in that light.

A. — As regards the *kind of current* to be employed, no official decision has been pronounced, but it is in my opinion highly probable that for Austria *single-phase current* will be decided upon.

The properties of single-phase current with respect to the line conductors and rolling stock have been thoroughly expounded in the technical press from all points of view.

A complete summary of the *pros* and *cons* of single-phase current from the service point of view was given in the treatise on the introduction of electric

traction on the Bavarian State Railways(1). It may be asserted that the technical service requirements are fully understood, except as regards exceptional cases.

It is more difficult to estimate how far the well-known properties of a given kind of current will fulfil the requirements imposed by service considerations. In spite of extensive experience in steam-traffic, the opinions in this respect differ, and this must be largely ascribed to different local conditions. But it must be emphasised that the service requirements (except where they are unnecessarily severe or out of date) must be respected and this can be easily done with electric traction which is adaptable to practically any set of conditions.

The service requirements relate to the line wires and rolling stock.

B. — The chief considerations in the case of the line wires relate to immunity from interruptions in the supply of current and to the safety of the railway staff. In addition to the essential requirement that the installation of the wires and conductors be carried out in a first-class manner, the following points should be kept in view :

a) Simplicity of design and the employment of as few parts as possible requiring attention and maintenance;

b) A complete system of feeders connecting the various power stations, the feeders being of such dimensions that when one power station fails, the nearest one can be utilised for maintaining at least a reduced passenger service;

c) In tunnels, through high hills or mountains (*e. g.* Arlberg & Tauern tunnels, and possibly also the Karawanken and Wocheiner tunnels) where the feeders cannot be carried round over the mountains, provision should be made for carrying the feeders through the tunnels. In such cases, overhead lines would seem to be out of the question on account of the danger involved in working in such tunnels, and also because the insulation would suffer by the deposit of moist dust on the underside of the insulators. In these cases, therefore, cables laid in protected troughs should be considered;

d) Where possible, the feeders should be carried along the line on the same poles that are used for the overhead line; this design would ensure better supervision and would be cheapest. Where this is not possible, the feeders should be carried along two separate tracks (with right-of-way); the tracks may either be quite distinct from one another, or else (when only one track is used) the feeders should be carried on two lines of poles which are sufficiently far apart to permit of work being carried out on one of the lines (after the current has been switched off) while the other is under tension;

e) The overhead lines should be suspended on the catenary principle, so as to prevent the falling of wires and consequent short-circuits as far as possible;

f) Fullest possible protection against atmospheric influences;

g) The height of the overhead wires above the rails should not be too small, particularly as steam locomotives may still have to be run in exceptional cases over electric lines. Recent mishaps have shown that firemen — through careless

(1) See *Elektrische Kraftbetriebe und Bahnen*, 1908, Nos. 13-19.

handling of their fire-hooks, etc. — may come into electric contact with the overhead wires. This is easily possible when the floor of the locomotive cab is from 1,200 to 1,700 millimetres (3 ft. 11 $^1/_4$ in. to 5 ft. 7 in.) above the rails and the fireman manipulates a fire-hook 3 metres long (9 ft. 10 in.) in a careless fashion.

The height of the overhead wire above rail level should therefore be at least 5 $^1/_2$ metres (18 ft. $^9/_{16}$ in.) in the case of full-gauge railways, and even higher in the larger stations;

h) Similarly, the poles should be sufficiently distant from the centre of the track to allow a man to stand between the moving train and the pole. For the rest, for stations that design should be chosen which requires the minimum number of poles;

i) It should be possible to start easily and promptly from any position in the station.

C. — As regards the design of the motors and rolling stock, the following service requirements must be met :

a) Simple design and durable construction;

b) Small weight;

c) Accessibility and facility of renewing parts;

d) Complete protection against dust and weather;

e) Large continuous tractive effort and large overload capacity;

f) Large starting torque;

g) High efficiency and large torque even when the supply voltage drops and when the speed changes (it is just when the service is severe after delays that high speeds and large tractive efforts must be developed);

h) Uniform working (as far as possible) of all the motors of a motor-car;

i) Uniform working (as far as possible) of all the motors of a train;

k) Simplest possible arrangement for adjusting the speed (from the service point of view it is of no moment whether the motors maintain a constant speed with varying load, or change in speed, according to the gradient, with constant output;

l) Minimum maintenance costs;

m) Fewest possible number of different motorcar or locomotive types for hauling all kinds of trains;

n) Each motorcar or locomotive should have a drivers' compartment at both ends, connected by a passage; it should be possible to pass without danger from one car to another during the journey;

o) Cars which are coupled to form a train should be controlled on the multiple-unit system from the driver's compartment.

In order to reduce the capital and running costs, the following commercial requirements should be met :

a) High line voltage (so as to reduce the transmission losses and the number of sub-stations required);

b) As uniform a load on the motors as possible by suitable regulation of the speed (slow speed on up-gradients, high speed on the level).

D. — All the above requirements are met by the single-phase system.

Valid objections might only be raised on the following two points :

1° *Large starting torque.* — The ad-

vantages possessed in this respect by the three-phase system (when using normal voltages) and the continous-current system are not very important from the service point of view, because the useful tractive effort is limited to certain values depending on adhesion, and even with sanding the ratio cannot be depended upon to be higher than 1 : 3. This limit can be attained with single-phase motors. On the other side, the advantage of a large torque with three-phase motors is neutralised by the fact that the torque depends on the line voltage. It is better to be sure of a torque which is but little in excess of the torque required, but which can be maintained under all conditions by means of a regulating transformer, than to have a large excess of torque at normal voltages, but a considerable decrease when the voltage drops.

The advantage possessed by single-phase motors of maintaining and even increasing their speed with constant torque (even when the voltage drops) is altogether lacking in the other two systems, at least in the usual designs;

Chief advantages of the single-phase system.

Only one overhead wire.

Wide range of speed regulation.

Different cars will work well together, although they may not have been originally intended for such purpose.

The possibility of running single-phase cars or trains over three-phase lines.

Smaller capital costs.

2° Small weight of the motorcars and locomotives. In this respect, the single-phase system will always remain at a disadvantage as compared with the two other systems. The chief saving in weight (as compared with steam traction) lies in the elimination of the tender. When the three-phase equipment is designed to give at least four speeds (being thus as regards speed regulation practically equivalent with the single-phase system), its advantage as regards weight is considerably lessened ; this remark is particularly applicable when the three-phase cascade system is resorted to for obtaining the different speeds.

A discussion in detail on the properties and possibilities of the three rival systems would increase this report to an undesirable extent, but I am of the opinion that the decision between the single-phase and three-phase systems (which alone need be seriously considered in the present state of electric propulsion) will depend on the weight which is attached to the properties briefly set forth below :

Chief advantages of the three-phase system.

Smaller weight of car for the same output.

The plans which have been prepared for the electrification of certain lines were based from the start on single-phase current of a line pressure of 10,000 volts and a frequency of 15 and $16\,^2/_3$ cycles per second.

E. — For the numerous lines in the Austrian mountain region, and for that matter in all full-gauge railways with many curves, it would seem important to place the centre of gravity of the cars

high, and to support the motors on springs so as to obtain quiet running on straight portions and a jerkless and reliable entrance of the cars into curves. The best mechanical arrangement for transmitting the power from the motors to the wheels is perhaps the Gölsdorf design with connecting rods, such as is used on the Valtellina railway. The employment of motors mounted on the axles is disadvantageous because of the hammering effect when the car passes over an uneveness in the track, and the spring suspension of such motors (where provided) is costly to maintain and inaccessible and renders the removal of the motors difficult. These disadvantage have been observed, for instance, with the locomotives of the Baltimore & Ohio Railway. A similar arrangement, in which, however, the large gear wheel and not the motor itself is mounted on a spring-suspended hollow shaft surrounding the axle, is employed in the latest locomotives of the New York, New Haven & Hartford Railway, but I am not aware of the reasons for adopting this arrangement.

F. — The use of *gear wheels* is not desirable for locomotives, but can hardly be avoided in the case of motor-cars. It would be interesting to see to what extent the pairing of gear wheels of different age (and therefore worn to different degrees) can be avoided in practice.

G. — The comparatively light rails used in the Austrian mountain districts, in conjunction with the numerous curves, make it desirable to use *radial axles* for all speeds above 40 kilometres (24·9 miles) per hour.

The curves in figures 3 and 4 show the calculated energy required for the main railways of the districts under investigation; they are also useful for the calculations for other lines. The State Railway network under consideration was divided into 171 sections and these were again sub-divided for the purpose of calculating the energy required. Figure 3 shows the watt-hours per ton-kilometre (including the locomotive) for goods trains; every point was obtained by an elaborate calculation. The assumed speeds are considerably higher than those now in vogue. Similar curves were plotted for express and passenger trains. All the plotted points lie near to an average curve, and the distance of a particular point from this average curve is a measure for the frequency, or otherwise, of starting on the route to which the point refers. These values were used for plotting figure 4, which shows average curves for one direction of travel and for both directions together. The calculations were based on average gradients, calculated from the difference in altitude of the termini and the intervening distance. These curves can be used quite generally, provided that the line to be investigated is sub-divided into sections which contain chiefly either up or down gradients.

b) Investigations by the Hungarian State Railways.

The Hungarian State Railway Administration has carried out investigations on several lines. In addition to the plans prepared for the Esztergom-Almás-Fűzitő line (with a maximum gradient of 1·6 per cent) and the Petrozsény-Piski line (for

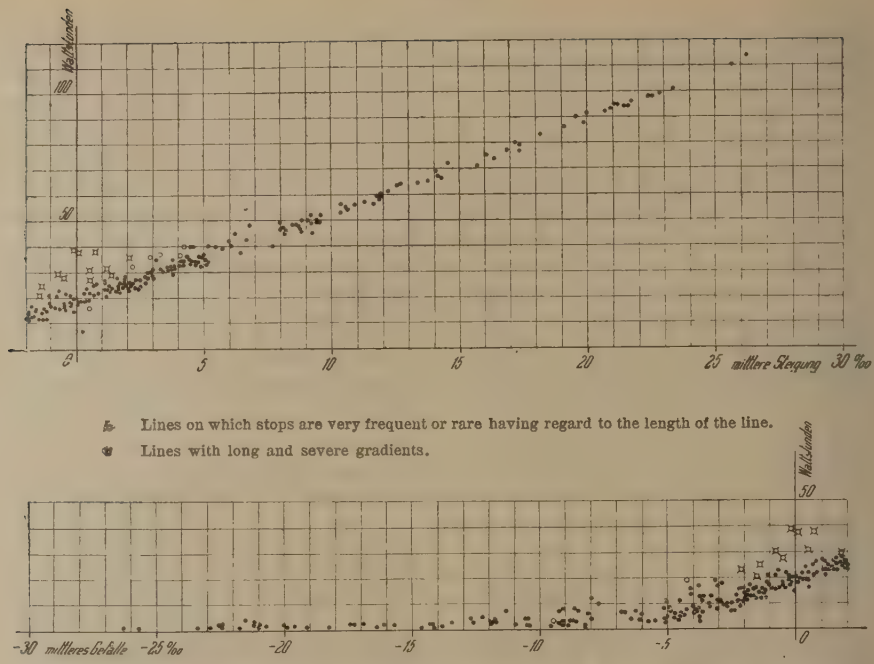


Fig. 3. — Calculated consumption, in watt-hours, measured at the current collectors, per train-kilometre for various average gradients (for goods trains on the Austrian State Railways).

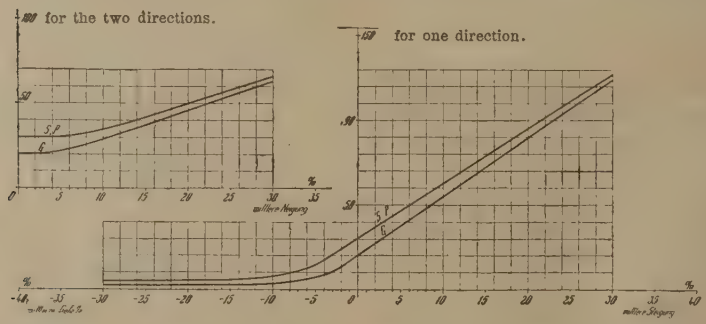


Fig. 4. — Energy consumption, in watt-hours, measured at the current collectors, per train-kilometre for various average gradients (according to calculations for the Austrian State Railways south of the Danube).

Explanation of German terms : Wattstunden = Watt-hours. — Mittlere Steigung = Average up gradient. Mittleres Gefälle = Average down gradient. — Mittlere Neigung = Average gradient.

which Messrs. Ganz & Co. have prepared a complete three-phase scheme), the only other plan deserving serious consideration at the present time, relates to the heavily-loaded main line from Fiume to Cameralmoravicza. This line forms a part of the Fiume-Budapest main line. It is 90 kilometres (56 miles) long, with many curves and tunnels, and has an up-gradient of 2·5 per cent over the larger portion of 35 kilometres (21·7 miles). The Brajdica-Buccari section, directly after Fiume, has many up gradients and a number of smoke-laden tunnels and would therefore be a very suitable object for electrification. Even at present, the traffic in both directions amounts to 15,800 gross-tons daily. Negociations have been opened with the French Adriatique-Electricité Company, which is willing to supply from their 80,000 horse-power station on the river Gacka near Spasovac in Croatia (50 kilometres [31 miles]) from Fiume, 2 million kilowatt-hours at a pressure of 50,000 volts for working this section. The whole line would require about 12 million kilowatt-hours per annum. The decision to use single-phase current at 10,000 volts and 15 cycles per second for the Vácz-Gödöllö line now building must, according to a communication from the Hungarian State Railways, by no means be regarded as a precedent as regards the choice of current for future Hungarian State lines; the final decision cannot be made until the investigations are further advanced.

c) **Investigations of the Südbahn Company.**

The Südbahn Company has only considered the electrification of their Kufstein-Ala and Marburg-Franzensfeste lines. This is due to the following considerations:

1° Water powers are available for these lines, and they can probably be utilised in a commercially satisfactory manner;

2° The question of electrification was considered from the strictly commercial point of view, and was more particularly concerned with the saving to be effected by doing away with the transport of fuel, saving in working and stock, reduction in the staff and saving of the power now lost in hauling the tender.

It is proposed to carry on the whole passenger and goods service of one of the lines by electric means, leaving the composition of the trains as they are at present. The kind of current to be employed has not yet been decided on, and in view of the fact that the locomotives run over neighbouring lines, this decision can probably only be made with the approval of the neighbouring lines. From the purely technical point of view, the company favours the three-phase system, the reason being that this system makes it possible to regain quite 30 per cent of the energy consumed in hauling the trains up the 2·5 per cent gradients (which form a considerable portion of the total length) when coasting downhill.

So far, the investigations have been limited to the calculation of the total energy required and to the selection of suitable water powers.

d) **Other plans and projects.**

A number of plans have been prepared for private lines, and it is probable that

*

they will be carried out in the next few years. Without claiming completeness, I may mention the following lines :

Vienna-Pozsony (Pressburg). — This full-gauge line is to be equipped for electric traction from the very beginning; it leads from the centre of Vienna, south of the Danube, to the Hungarian town of Pozsony. I was unable to obtain particulars as to the kind of current to be employed and as to the building programme.

Innsbruck-Mittenwald (Mittenwald railway). — This is to start at Innsbruck, and to proceed northwards to join the Mittenwald-Garmisch-Griesen line which is planned by the Bavarian railways. It is intended to operate this line with single-phase current which will be supplied from the Rutzbach power station; the latter is an extension of the already existing Sill power station belonging to the municipality of Innsbruck.

Niederösterreichische Landesbahnen. — In addition to the main line, it is intended later to electrify the following :

The single-track line Ober Grafendorf-Mank-Gresten, 60 kilometres (37·3 miles) long, with 75 centimetres (2 ft. 5 $^1/_2$ in.) gauge. The traffic is very light, and the reason for electrifying this portion is the desire to obtain uniformity in working; the conversion could only be made to pay by adopting the simplest arrangements possible.

It is also proposed to convert the Stammersdorf-Auersthal (-Schweinsbarth) line (22 kilometres [13·7 miles] long), which is at present operated by the municipality of Vienna by steam, to electric traction on the continuous-current system. The line voltage is to be from 800 to 1,000 volts, and the energy is to be supplied from a three-phase power station.

Nyiregyháza-Dombrád and Mezöhegyes-Kovácsháza lines. — These local lines have a length of 65 kilometres (40·4 miles) and are at present worked by means of petrol-electric motorcars. It is proposed to convert them to the high-tension single-phase or continuous-current system with overhead wires.

SUMMARY.

At the present time, there are only electric secondary and local lines in Austria and Hungary, two of which are operated by single-phase current at 2,500 and 550 volts respectively, while the others are worked with continuous current. Further lines, of an aggregate length of 150 kilometres (93·2 miles), are under construction; it is intended to operate them with single-phase current at 6,000 and 10,000 volts respectively, the frequencies suggested being 25 and 15 cycles per second. The economic importance of electric traction for main lines in Austria and Hungary, with its abundant water powers, has been fully realised, and has led to a thorough investigation of the problem, more particularly in Austria. The commencement of elec-

tric traction on a large scale will most probably result in the execution of large water power schemes by special companies formed for the sole purpose of generating and selling current—a feature which is at present not very marked in Austria and Hungary. The full utilisation of the available water powers, however, can only be achieved by using current both for traction purposes and electro-chemical purposes. Many lines will be converted to electric traction for purely technical reasons, whether the economic aspects be favourable or otherwise. All kinds of reasons for introducing electric traction are met with, e. g. the desire to effect a saving in the working costs, to eliminate the smoke nuisance, to improve the service by simplifying the time tables and to increase the carrying capacity by increasing the speed. It will be necessary to adhere to the usual compositions of the heavy express and goods trains, or even to make them heavier, but it will be quite possible to split up the passenger trains into smaller units, even on single-track lines.

The Austrian State Railways Administration has nominated a special department to study the present and future technical and economic aspects of electric traction on a network of 4,340 kilometres (2,697 miles), within the range of the available water powers; this investigation is partly completed. The total energy required has been calculated, and it is now possible to indicate which of the large sources of water power will be required in future for railway purposes and which can be left absolutely for industrial purposes. The State Railways Administration will conclude agreements with prospective water power companies, with the object of securing the option of using a certain portion of the water power for its own purposes. The idea is to combine the supply of current for railway, power and lighting purposes in such a manner as to obtain the most economical results.

In most cases, the Railway Administration and the private companies with which it is in negotiation, have the intention of adding a steam or gas-driven plant to the water-power installation, so as to provide a reserve, when the water-power plant is shut down, or when the quantity of water is insufficient. The total cost of current will not be substantially increased by such reserve plants, as such increase is mainly a question of the fuel costs during certain periods of the year. As a general rule, full-gauge railways can be worked with economical results, if the price per kilometre-hour ranges between a fraction of a heller and a few hellers at most. Although the capital costs of water-power plants in the Austrian Alps are not inconsiderable, and in spite of the fact that the conditions for building large water reservoirs are rarely favourable, there is no doubt that the electrification of the long gradients will yield economical results; in the case of short gradients, the results will be adversely affected by the high peak loads and the fact that the locomotives are not constantly fully loaded.

In all cases the ultimate financial result will depend on the maintenance and renewal costs.

The Austrian State Railways Administration is preparing detailed plans for lines aggregating 1,000 kilometres (621 miles);

the plans for some of the main lines are already completed. It is probable that the Trieste-Opcina line (for service considerations) and the Arlberg railway (for economic reasons) will be first converted to electric traction. Investigations are also being made by the Hungarian State Railways and by the Südbahn company; the latter has calculated the energy required for its main line railway network (totalling 1,500 kilometres [932 miles]) situated in Austria, and a commencement will probably be made with the conversion of a long main line in a mountainous district.

The problem as to the best kind of current to be employed, will probably be decided in Austria in favour of single-phase-current at 10,000 volt line pressure and fifteen to sixteen cycles per second; this choice will be governed by the following three considerations. Simple overhead construction, elastic speed regulation and low installation costs.

APPENDIX I.

Description of the electric full-gauge railways in operation.

Bludenz-Schruns (1).

This full-gauge single-track local railway is 12·506 kilometres (7·771 miles) long, and is worked by the Austrian State Railways for the A. G. Montafonerbahn, the owners. It runs through the Montafon valley and connects the station of Bludenz (on the Innsbruk-Lindau main line) with the small village of Schruns. The steepest gradient is 2·6 per cent and the sharpest curve has a radius of 100 metres (5 chains); 93 per cent of the line is in gradients. The rails weigh 21·8 kilograms per metre (43·9 lb. per yard). There are altogether seven stopping places.

Continuous current at 500 volts is supplied from the Montafon Electricity Works at Schruns. The overhead wire has a cross-section of 50 square millimetres (0·077 square inch) and is suspended at a height of 5 ½ metres (18 ft. 9/16 in.) The maximum speed is 30 kilometres per hour; in curves with a radius of less than 150 metres [7 ½ chains] 20 kilometres [12·4 miles] per hour. There are two motor cars, one passenger carriage and two goods cars.

The motor cars are provided with two axles, each of which is driven through gearing (as in tramcars) by a motor developing 20 horse-power on the one hours' rating; there is seating accommodation for thirty-two passengers; standing room for eighteen passengers and a luggage compartment. The cost of each motor-car was 43,900 kronen (£1,825). The passenger carriage has seating accommodation for fifty and standing room for twenty passengers, weight, 9·7 tons (9·5 English tons), price 11,900 kronen (£495). The goods cars have a loading capacity of 7·5 tons (7·4 English tons). A repair car and snow-plough are also provided. In winter, the snow must be occasionally removed by steam locomotives.

The line was inaugurated on the 18 December 1905. The electric equipment was supplied by the Austrian Siemens-Schuckert Werke.

In 1907 4,871 trains, 85,901 passengers and 10,103 tons (9,943 English tons) of goods were dealt with, corresponding to 272,322 axle-kilometres (169,216 axle-miles), 62,378 motor-car-kilometres (38,760 motor-car-miles), (30,386 [18,881 miles] per motor-car), 60,799 train-kilometres (37,780 train-miles), 1,537,187 gross ton-kilometres (970,509 English ton-miles) and 1,721,900 gross ton-kilometres (1,087,129 English ton-miles). The average train weight was 28 tons (27·5 English tons).

The expenditure was as follows : General management 1,987 kronen (£82.13*s.*), maintenance of railway and supervision 15,355 kronen (£639.5*s.*) of which 4,591 kronen (£191) was for the permanent way, haulage 13,644 kronen (£567.12*s.*) (21·9 heller per motorcar-kilometre [3·50*d.* per motor-car-mile], general traffic and commercial expenses 10,734 kronen (£446.11*s.*), miscellaneous 12,070 kronen (£502.2*s.*), or a total of 53,790 kronen (£2,237.13*s.*), corresponding to 86·3 heller per motor-car-kilometre (13·87*d.* per motor-car-mile).

The receipts amounted to 86,339 kronen (£3,591.14*s.*), so that the ratio of expenditure to revenue was 62·4 per cent. In 1908 (with a larger passenger traffic, but reduced goods traffic) this ratio increased to 65·5 per cent; in 1906 it was as low as 41·5 per cent. In 1907 the amount available for distribution allowed a dividend of 2 per cent to be paid on the ordinary shares and 4 per cent on the preference shares.

(1) See *Electrotechnische Zeitschrift*, 1905, p. 630.

Tabor-Bechyn (1).

The characteristic feature of this line is that it is operated on the 3-wire continuous-current system (2 × 700 volts).

This full-gauge, single-track, local railway (23·595 kilometres [14·662 miles] long) connects Tabor (a station of the State Railways) in Bohemia with Bechyn, and is worked by the Austrian State Railways for the owners. There are eleven stopping places. The maximum gradient is 3·5 per cent, and the sharpest curve has a radius of 125 metres (6 1/4 chains); 82 per cent of the line lies in gradients. The rails weigh 21·75 kilograms per metre (43·84 lb. per yard).

The line was originally planned for steam traction with a maximum gradient of 2·5 per cent; by adopting electric traction, however, considerably steeper gradients could be allowed and the smaller weight of the motor-cars permitted the weight of the rails to be reduced by 8 1/2 kilograms per metre (17·13 lb. per yard).

The three-wire continuous-current system (which is similar to that adopted on the Grenoble-Chapareillau and St. Georges de Commiers-La Mure lines) possesses some advantages. Not only does the higher voltage result in a reduction of the copper in the conductors, but the fact of being independent of the state of the contact between the wheels and the rail (when the latter are covered with ice or snow) is a practical advantage. On the other hand, the double overhead line implies a certain complication of the overhead equipment which, however, is only appreciable when there is a considerable number of sidings.

The advantage that traffic can still be carried on when one wire breaks, is only apparent, because the possible points of failure are twice as many as in a single line.

Current is supplied from the Tabor Electricity Works (situated on the railway at a distance of 1·2 kilometre (0·75 mile) from the terminus) which is equipped with three boilers, having a heating surface of 80 square metres (861 square feet) each. These boilers supply superheated steam 300° C. (572° Fahr.) at a pressure of 11 atmospheres to three 120 horse-power vertical compound engines.

There are two 80 kilowatt railway generators, supplying current at 2 × 700 volts when running at 500 revolutions per minute, and two 500-volt generators for supplying current for lighting to the town of Tabor. A Tudor accumulator battery (700 cells) of a capacity of 123 and 171 ampere-hours at the one hours and three hours' rating respectively, serves for splitting the voltage and for equalising the load.

The main generators are excited from one side of the three-wire system (see fig. 5). There are also two double-generators (acting as boosters) designed for 80 amperes and 2 × 90 volts when rotating at 1,100 revolutions per minute; they are belt-driven from the shafts of the main generators and serve to increase the voltage in the feeders for the more distant points. These generators are provided with shunt regulation and are capable of giving a maximum boost of 2 × 116 volts at full load for the feeders which supply the second section of the line with current. If desired, the first section of the line can also be supplied with current at a higher pressure than normal. The boosters are provided with automatic short-circuiting devices for armature and field, in order to prevent them assuming a dangerously high speed should the belts come off, a contingency which might otherwise occur as they are series-wound machines. Before commencing to race, however, the booster would have to change its direction of rotation, and the short-circuiting device is so arranged as to come into action when the speed has dropped to a predetermined value.

The double overhead line consist of two copper wires of 64 square millimetre (0.1007 square inch) section each. They are suspended at a height of 5 1/2 metres (18 ft. 9/16 in.) and the two wires are 1·2 metres (3 ft. 11 1/4 in.) apart. The wires are supported by span wires, stretched

(1) Treatise by Messrs. Fr. Kržik entitled *Elektrische Lokalbahn Tabor-Bechyn*, 1904.

between wooden poles, the latter being spaced at intervals not exceeding 40 metres (44 yards). The overhead line is divided into two sections; the firs section is directly supplied with current from the generators and battery, while the second section is supplied through four feeders, consisting of copper wires of 50 square millimetres (0·0775 square inch) cross-section each. As already mentioned, the feeder voltage is increased by means of the boosters. The cross-section of each of the overhead wires in the second section is 35 square millimetres (0·0542 square inch) larger than in the first section. When the two sides of the three wire system are unequally loaded, part of the current returns through the rails which are connected with one another at the joints by means of copper bonds 7 millimetres ($^{9}/_{32}$ inch) in diameter.

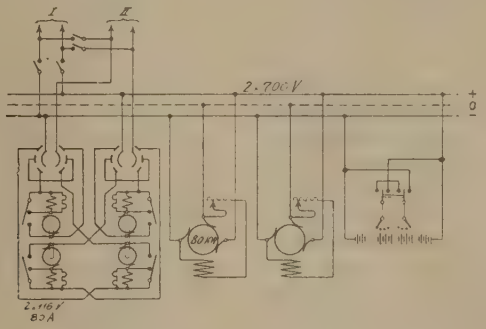


Fig. 5. — Diagram of connections in the Tabor power station of the Tabor-Bechyn line.

In 1907, the rolling stock consisted of three motor-cars and twenty goods cars, the average weight of the latter being 7·7 tons (7·6 English tons).

The motor-cars have four axles. Each has seating accommodation for forty-three passengers and is provided with a luggage compartment. The total length of the motor-car is 12.86 metres (42 ft. 2 $^{5}/_{16}$ in.) and its weight (empty) is 18·8 tons (18·5 English tons) of which 13·5 tons (13·2 English tons) correspond to the mechanical portion and 5·3 tons (5·2 English tons) to the electrical part. Current is collected from the overhead wires by two bow collectors (one for each wire) which are suitably staggered. Each motor-car is driven through gearing by four continuous-current series motors, each of which is capable of developing 30 horse-power on the one hours' rating. The motors are provided with four poles and the armature has sixty-one slots (9 millimetres [$^{11}/_{32}$ inch] wide and 33 millimetres [1 $^{5}/_{16}$ inches] deep); the air gap is 4 millimetres ($^{5}/_{32}$ inch) and the current is fed to the commutator by means of four carbon brushes. The gear ratio is 1 : 5·75. The weight of a motor complete with gearing and gear case is 935 kilogrammes (2,061 lb.) corresponding to 31·2 kilogrammes per horse-power (68·8 lb. per British horse-power) on the one hours' rating. The maximum speed is 30 kilometres (18·6 miles) per hour, but on the steepest gradients and in curves with a smaller radius than 150 metres (7 $^{1}/_{2}$ chains) the maximum speed is 15 kilometres (9·3 miles) per hour.

The speed regulation is on the series-parallel system and is effected by two controllers with magnetic blow-out. The four motors are permanently divided into two groups. At starting, the two motors of each group, together with a suitable starting resistance, are first connected in series, and then in parallel across one side of the three wire system; two further steps

are obtained by weakening the motor fields.

There are altogether eight running positions and six braking positions (the electric braking is obtained by short-circuiting the two parallel-connected motors of each group).

The motor-cars are heated by making use of the starting resistances in conjunction with special radiators.

The price of each motorcar was 36,699 kronen (£1,516.14*s.*). Not more than two trains, weighing 56 tons (55·1 English tons) each, are ever simultaneously in service. The service was commenced on 22 June 1903. The electric equipment was supplied by Fr. Křižík, of Prague.

The installation costs in 1907 were as follows :

for building and equipping the railway	2,171,836 kronen	(£90,348. 8*s.*).
for the rolling stock	156,929 —	(£6,528. 4*s.*).
	2,328,765 kronen	(£96,876.12*s.*).

In 1907, 60,731 passengers and 11,958 tons (11,769 English tons) of goods were carried ; this corresponds to 410,288 axle-kilometres (254,946 axle-miles), 75,269 motorcar-kilometres (46,770 motocar-miles) (25,076 [15,582 miles] per motorcar), 75,227 train-kilometres (46,745 train-miles), 1,909,328 net ton-kilometres and 2,280,800 gross ton-kilometres (1,205,462 and 1,439,992 English ton-miles). On an average sixteen trains were run daily, the average train weight being 30 tons (29·5 English tons).

The working costs were as follows : General costs of administration 3,928 kronen (£163.8*s.*), maintenance and supervision of railway 19,126 kronen (£795.13*s.*), train haulage 45,591 kronen (£1,896.12*s.*), general service and commercial expenses 13,848 kronen (£576.2*s.*), miscellaneous 20,465 kronen (£851.7*s.*) or a total of 102,958 kronen (£4,283.1*s.*) (1·36 kronen per motorcar-kilometre [1*s.* 9·78*d.* per motocar-mile]).

The total receipts amounted only to 73,397 kronen (£3,053.6*s.*) (54 per cent of which were from the passenger traffic), and the ratio of expenditure to receipts was therefore 140 p. c. The loss was made good by the government of Bohemia contributing a guaranteed subsidy of 130,615 kronen (£5,433.12*s.*) (corresponding to 5·38 per cent of the capital expenditure).

The more important technical and commercial results since the opening of this railway are as follows :

YEAR.	1904.	1905.	1906.	1907.	1908.
Passengers carried	46,409	50,864	57,341	60,731	
Goods carried (tons)	8,552	7,610	9,925	11,958	
Gross ton-kilometer	1,879,100	1,988,200	2,140,500	2,280,800	
Running costs :	Kronen.	Kronen.	Kronen.	Kronen.	Kronen.
General administration	2,944	3,697	3,629	3,928	3,997
Railway maintenance and supervision.	10,125	13,202	14,353	19,126	26,572
Train haulage	36,587	47,771	45,297	45,591	40,559
General service and commercial expenses	12,158	12,980	12,938	13,848	12,814
Total running costs	61,814	77,650	76,217	82,493	83,942
Miscellaneous expenses	...	4,382	4,544	20,465	?
Receipts	79,433	80,949	90,043	73,397	77,592
Running costs in per cent of receipts .	77·9	96·1	84·6	112·5	108
Yearly subsidy from Bohemian government	77,052	95,364	88,840	130,615	...

In spite of increasing traffic, the financial results have grown worse. Such unsatisfactory financial results are, however, not infrequently met with in local steam railways (in 1907, for instance, out of 146 Austrian local railways of a total length of 5,694 kilometres (3,538 miles), 26 have shown a loss, while 32 other railways were obliged to accept a State subsidy in order to pay their financial obligations) and the reason must be looked for in local conditions. It may be confidently asserted that the Tabor-Bechyn line would have shown even worse results with steam traction.

Innsbruck-Fulpmes Stubaital Railway (1).

The *characteristic feature* of this local railway (gauge, 1 metre [3 ft. 3 3/8 in.]) is that it is operated by high-tension single-phase current of high frequency; it is the first Austrian railway to be worked with high-tension single-phase current. Air-pressure brakes of the Böker system; Winter-Eichberg low-tension motors.

This single-track local railway was mentioned and illustrated in the Reports to the seventh session of the International Railway Congress (2). The line runs from Innsbruck through the Stubai valley to Fulpmes, 1,006 metres (3,280 ft. 11 in.) above sea level. It is 18·164 kilometres (11·287 miles) long; the maximum gradient is 4·6 per cent and the sharpest curve has a radius of 40 metres (2 chains). There are eleven stopping places and two tunnels of which the longer one has a length of 157·5 metres (172·2 yards). Weight of rails : 17·89 kilogrammes per metre (36·06 lb. per yard. Maximum speed, 25 kilometres (15·5 miles) per hour.

The line was originally planned for steam traction. However, the financial advantages of electric traction (by reason of the steep gradients and high fuel costs in the Tyrol) were recognised in good time, but it was first intended to adopt the continuous-current system at 600 volts. Finally, however, the lack of sufficient capital led to the decision to adopt high-tension single-phase current — no doubt the best and cheapest system in this particular case.

Current is obtained from the Sill Electricity Works (the property of the town of Innsbruck) where two phase current at 10,000 volts and 42 1/2 cycles per second is generated. The single-phase current for operating the railway can be obtained from the one or the other side of the supply network according to requirements. In order to prevent sharp voltage fluctuations in the lighting mains to Innsbruck, there is installed, at the point where the mains branch off to the railway, a boosting transformer which increases the voltage in proportion to the current taken by the railway. At the beginning, nevertheless, the light fluctuated in Insbruck whenever a train started in spite of the fact that the energy required for the railway was only a small fraction of the generator capacity. This was due to the fact that the 3,000 horse-power generating sets of the Electricity Works were at that time only very lightly loaded, in consequence of which the voltage ranged on the lower part of the voltage characteristic (below the bend). This undesirable feature has automatically disappeared with increased load on the power station.

There are two feeding points (at a distance of 2·3 and 16 kilometres [1·4 and 10 miles] respectively from the terminus) at each of which there are three 75 kilowatt oil-cooled transformers, one being a reserve. The feeder line is 16 kilometres (10 miles) long, its section being 2 × 35 square millimetres (0·0542 square inch) throughout. The double-pole fuses of the transformers only act on short-circuit; the supply is switched off when an overload occurs (the price paid for the electrical energy is based on a maximum

(1) See the article entitled « Die Stubaitalbahn », by Dr E. F. Seefehlner, which appeared in *Elektrische Kraftbetriebe und Bahnen*, 1906, Nos. 35 and 36; a description of the motors was published in *Elektrische Kraftbetriebe und Bahnen*, 1905, p. 294.

(2) See *Bulletin of the Railway Congress*, Number of October, 1905, p. 2137, reporter : Victor Tremontani.

current which must not be exceeded) by automatic circuit breakers with bell signal. The circuit-breakers are closed again by the station employee in attendance.

The overhead wires are suspended on the catenary principle, the points of support being 4 metres (13 ft. 1 1/2 in.) apart. The maximum span is 50 metres (164 feet).

The cross-section is 53 square millimetres (0·0821 square inch) and the height of the wires above rails ranges from 5 1/2 metres (18 ft. 9/16 in.) in the open down to 3·9 metres (12 ft. 9 9/16 in.) in the tunnels. The line pressure is 2,500 volts. The tunnels are narrow (being originally built for a third rail) and in order to prevent the bow collectors from touching the walls, guard wires have been erected at each side of the overhead wire.

The capital outlay for the feeder and overhead lines, including steel catenary cables and brackets, amounted to 50,000 kronen (£2,080). If the three-phase system had been adopted the copper alone would have cost 69,000 kronen (£2,870.8*s*.), while in the case of the continuous-current system the third rail of crucible steel would have cost 80,000 kronen (£3,328).

The rolling stock consists of four motor-cars, six passenger carriages, one post van and thirteen goods wagons. The maximum weight of a train (with two trailers) is 34 tons (33·4 English tons) empty and 45 tons (44·2 English tons) fully loaded.

Each motor-car has four axles and provides seating accommodation for thirty-six passengers and standing room for twenty passengers. Its net weight is 20 tons in round figures. The maximum output of all the motors of a train is 200 horse-power. Each motor-car is equipped with four 6-pole Winter-Eichberg single-phase motors, wound for a voltage of 625 volts and capable of developing 40 horse-power on the one hours' rating. The power of the motors, which are of the totally-enclosed type, is transmitted through gearing (ratio 1 : 6) to the axles. All four motors work in parallel.

The wheel base of the bogies is 2 metres (6 ft. 6 3/4 in.) and the distance between the centres about which the bogies train is 5 1/2 metres (18 ft. 1/2 in.).

Overall length of motor-car 11 metres (36 ft. 1 in.); diameter of wheels 800 millimetres (2 ft. 7 1/2 in.). The weight of a bogie with wheels and motor suspension gear is 2·3 tons (2·2 English tons).

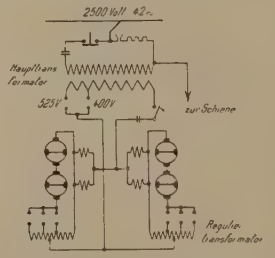


Fig. 6. — Diagram of connections of the motor-coaches on the Innsbruck-Fulpmes lines.

Explanation of German terms: Haupttransformator = Main transformer. — Reguliertransformator = Regulating transformer. — Zur Schiene = To rails.

The diagram of connections (fig. 6) is very simple. The four motors are divided into two groups of two motors each, and each group can be separately disconnected by means of a switch. Current is collected from the overhead wire by means of a bow collector which is mounted on

porcelain insulators. It can be raised and lowered by a rope (hemp) which is in two parts, electrically insulated from one another, and can be wound up on a drum. The high tension current from the bow collector is led into the car by means of a single lead-covered cable with earthed armouring. This cable leads to the main oil switch which can be operated by the driver. The compartment containing the high-tension apparatus can only be opened after this switch has been opened. The line pressure (2,500 volts) can be reduced to 400 or 525 volts by means of a large oil-cooled transformer weighing 1 ton. Two air-cooled transformers, weighing 250 kilograms (551 lb.) each, are provided to supply current to the armatures at three different voltages. The controller has therefore six running positions. The speed regulation is very efficient, as no starting resistances need be employed.

The passenger carriages are lighted and heated (at 500 volts) by electricity.

Compressed-air brakes of the Böker type are used in ordinary service. Originally, the compressed-air was produced in air compressors (driven from the axles) on the trailers, but later on special motor-driven air compressors were provided on the motorcars in order to avoid having to manœuvre to and fro before starting which was often necessary for the purpose of obtaining compressed-air. The brake is automatic.

Each motor-car cost 59,425 kronen (£2,472.2*s.*).

The trailers, which are provided with radial axles, weigh 6·7 tons (6·6 English tons) each; they have seating capacity for forty passengers and standing room for fifteen passengers. The post van weighs 3 ½ tons (3·44 English tons). The goods wagons have partly two axles (weight 3·34 tons [3·29 English tons] net, loading capacity 6 tons) and partly three axles with movable centre axle (net weight 5·2 and 5·5 tons [5·1 and 5·4 English tons] carrying capacity 10 tons [9·8 English tons]).

All carriages for carrying passengers are covered with an earthed net of metal as a protection against the possible consequences of a breakage of the overhead wire.

The rolling-stock is housed in the workshop at Wilten near Innsbruck and in a shed in Fulpmes. The workshop is 55 metres (180 ft. 5 in.) long and has an area of 715 square metres (7,696 square feet); it is provided with three tracks and can accommodate ten cars. The shed at Fulpmes affords room for two carriages.

The service was inaugurated on the 1 of August, 1904. The electrical equipment was supplied by the A. E. G. Union Company of Vienna.

In 1908, 120,941 passengers and 7,004 tons (6,893 English tons) of goods were carried, corresponding to 109,130 motor-car-kilometres (train-kilometre) (67,811 motor-car-miles [train-miles]) and 111,412 trailer-kilometres (69,229 trailer-miles) and 2,725,781 gross ton-kilometres (1,720,932 English ton-miles). On an average, each motor-car travelled 27,282 kilometres (16,95·3 miles) during the year. The number of trains per day ranged up to 24 (in summer).

The energy consumption per ton-kilometre (measured on the railway side of the transformers at the feeding points) amounted to 70 watt-hours. The overall efficiency, as calculated from this figure and the work done at the periphery of the driving wheels, came to 66·5 per cent. The train resistance was found to be 6·5 kilograms per ton (14·56 lb. per English ton).

At the beginning, serious disturbances were occasioned in most of the state-owned telephone and telegraph lines radiating from Innsbruck. The impedance of the overhead line was found to be 0·91 ohm per kilometre (1·46 ohms per mile); this high value is due to the high frequency of the single-phase current. Near Innsbruck the line approaches to within 300 metres (328 yards) of the telephone and telegraph lines, and as there are sharp S-curves in this part of the railway the voltage drop in the rails, amounting to over 10 volts, has a very disturbing effect. According to experiments carried out by the Zurich district administration and the Oerli-

kon Company on Swiss installations, the telephones, relays and signal bells begin to hum at 2, 6·5 and 2 ½ volts respectively, the frequency employed in the tests being fifty cycles per second. In the present case, continual disturbances were caused by capacity effects, and occasional disturbances were caused by inductive effects arising from sharp fluctuations in the current. Matters were improved by converting the single-wire telephone and telegraph lines within the sphere of influence of the railway to double lines; the second wire was earthed at a point where the disturbing effects from the railway ceased. Further, the feeders were strengthened and the equipment at the second feeding point (16 kilometres [10 miles] from the terminus) was altered. The service telephone line, which was originally carried along the railway, was replaced by a line at a suitable distance from the railway, and the results obtained were so satisfactory that no further attempts at improvements were found necessary.

The capital expediture on the railway was as follows :

Building and installation costs of railway . . .	2,455,919 kronen	(£102,166. 5*s*.).
Rolling stock.	352,751 —	(£14,674. 9*s*.).
	2,808,670 kronen	(£116,840.14*s*.).

The service expenditure during 1908 was as follows :

General administration 6,423 kronen (£267 2*s*.), supervision and maintenance of railway 11,283 kronen (£469.7*s*.) train haulage 50,308 kronen (£2,092.16*s*.), general service and commercial expenses 24,567 kronen (£1,022) miscellaneous 14,171 kronen (£589.10*s*.); therefore, the total working costs came to 106,752 kronen (£4,440.18*s*.), or 97·7 heller per motorcar-kilometre (1 s. 3·70*d*. per motorcar-mile) (train-kilometre).

On the other hand, the receipts amounted to 179,582 kronen (£7,470.12*s*.) (of which 79 per cent was obtained from passenger traffic) so that the ratio of expenditure to receipts is 59·4 per cent.

The separate items of the running costs during 1908 are as follows :

Maintenance of the transmission lines.	857 kronen	(£35.13*s*.).
Wages of transformer attendants	1,518 —	(£63. 3*s*.).
Maintenance of transformer sub-stations	247 —	(£10. 6*s*.).
Cost of current (8 ⅓ per cent of the running costs . . .	9,088 —	(£378. 1*s*.).
Lubrication and cleaning of motorcars	1,433 —	(£59.12*s*.).
Drivers wages	4,876 —	(£202.17*s*.).
Work shop (material and wages)	28,568 —	(£1,188. 9*s*.).

In 1907, both the passenger and goods traffic were heavier, and the ratio was only 55·2 per cent. The wages and salaries 1907 came to 42 heller per motorcar-kilometre (6·75*d*. per motorcar-mile) *i. e.* half of the running costs. The employees were distributed as follows : For railway maintenance twelve, for train service nine, for general service eighteen. The profits allowed a dividend of 4 ½ per cent to be distributed.

By comparing the running costs of this railway in 1907 with those of the adjoining Innsbruck- Hall line during 1904 (at which time this railway was exclusively operated by steam) it is found that the running expenses of the electrical line come to 2·58 hellers per ton-kilometre as against 8·84 (0·4212*d*. as against 1·4432*d*. per English ton-mile) in the case of the steam-operated line. The latter resembles the Stubaital railway as regards terrain difficulties, but the max. gradient is only 2 per cent.

The following table contains the chief technical and commercial particulars of the Stubaital railway since its inauguration :

YEAR.	1905.	1906.	1907.	1908.
Passengers carried	107,690	121,505	127,050	120,941
Goods carried (tons)	5,171	5,358	6,175	7,004
Gross ton-kilometres	...	2,678,521	3,463,601	2,725,781
Running costs, in kronen :				
General administration	5,794	5,862	6,030	6,423
Railway supervision and maintenance	11,353	12,056	20,913	11,283
Train haulage	35,614	34,208	39,621	50,308
General service and commercial expenses	20,597	21,531	22,614	24,567
Total running costs proper	73,358	73,657	89,178	92,581
Miscellaneous service expenses	3,865	10,574	11,891	14,171
Receipts	173,138	176,009	183,319	179,582
Running costs proper in per cent of receipts	42·3	41·8	48·6	46·0
Maintenance and conversion of the motor-coaches in kronen (and in per cent of capital cost)	7,646 (3·23)	7,172 (3·03)	12,878 (5·45)	22,823 (9·65)
Mileage (in kilometres) per motor-coach per annum	24,677	26,355	26,427	27,282

Vienna-Baden (1).

Characteristic features. — This interurban line between Vienna and Baden (terminating within the city boundary at each end) was originally worked by steam traction. It is 28·721 kilometres (17·847 miles) long. The heavy passenger traffic is carried on by means of motor-coaches, while the goods traffic is performed by steam locomotives. The motor-coaches are run at high speeds in the open and are operated by single-phase current at 550 volts. At and near the termini continuous current at 550 volts is employed, and the speeds are lower. The same motors are employed for both kinds of current, but there are two different sets of auxiliary apparatus on the coaches. The alternators at the power house are designed for 10,000 volts. A common buffer-action on the single-phase and continuous-current sides is obtained by employing flywheels and an accumulator battery. The coaches are lighted by single-phase current at 15 cyles per second. Vacuum brakes (with electrically driven vacuum pumps) are provided and the braking effect can be adjusted to a nicety. Short-circuit brakes. The signal horns are set in action by the exhaust from the vacuum pumps.

General remarks. — The line is the property of the Aktiengesellschaft der Wiener Lokalbahnen and leads from the Giselastrasse station (close to the Opera House) in Vienna viâ Matzleinsdorf into flat country, terminating in the town of Baden. The open portion of the line, measuring 20·36 kilometres (12·65 miles), in length, is operated by single-phase current at 550 volts and 15 cycles per second. The end portions, measuring 6·48 and 2·58 kilometres (4·25 and 1·60 miles) respectively, are worked by continuous current at the same voltage.

Standard gauge. Max. gradient 2·748 per cent; the sharpest curve has a radius of 18 metres (0·9 chain). The profile of the line is shown in figure 7.

(1) « Die elektrische Wechselstrombahn Wien-Baden », by L. Kadrnozka, published in *Elektrotechnik und Maschinenbau*, 1907, p. 803; *Elektrotechnische Zeitschrift*, 1906, p. 1151.

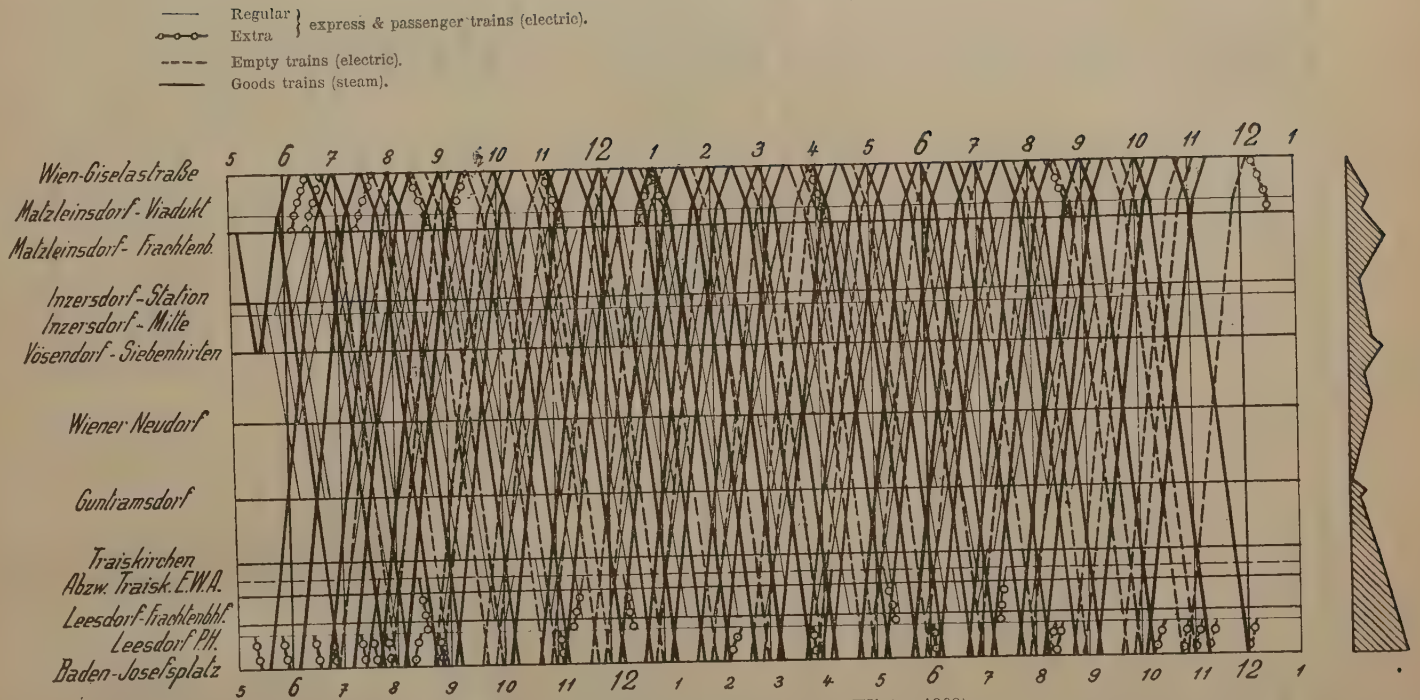


Fig. 7. — Time table of Vienna-Baden line (Winter 1909).

Explanation of German terms : Wien = Vienna. — Abzw. = Bifurcation.

Of the total length, 2·15 kilometres (1·34 miles) are single track and 27·63 kilometres (17·17 miles) double track; 22·14 kilometres (13·76 miles) of line are level, 7·64 kilometres (4 75 miles) of the line lie in curves. Grooved rails (Phœnix rails, weighing 50·1 kilograms per metre (101 lb. per yard) are employed for a length of 6·33 kilometres (3·99 miles) and round headed rails (26 kilograms per metre [52·4 lb. per yard]) are used on 23·45 kilometres (14·57 miles) of line.

The Guntramsdorf-Baden section was opened for electric traction on the 11 May, 1899 and the remainder was inaugurated on the 1 May, 1907.

The same company also runs the (Baden)-Tribuswinkel-Josefstal-Traiskirchen railway (which has more or less the character of a tramway), the Baden-Rauhenstein-Vöslau line and the Baden Ring railway. None of these secondary lines will be described below.

Reasons for adopting electric traction. — The line was at its opening in 1886 intended exclusively for goods traffic and later on goods traffic predominated. For a long time the passenger traffic did not gain appreciably in volume, because there were no facilities for bringing passengers to the original terminal points, viz. Guntramsdorf and Matzleinsdorf (a remote suburb of Vienna). In 1896 and the following years the Matzleinsdorf-Guntramsdorf section was operated by steam, while the extension to Baden, which was added to promote passenger traffic, was worked by electricity. But even this did not improve matters to any great extent until the line was brought right into the centre of Vienna and electric traction at increased speeds, adopted over the whole line. The traffic and the receipts then increased to such a degree that the competition from the Südbahn railway between Vienna and Baden was no longer to be feared.

The goods traffic, which is still carried on with steam traction, undergoes heavy fluctuations during the year. Bricks form the largest portion of the goods dealt with.

Comparative calculations have shown that the single-phase system on the open portion of the line is somewhat more economical than continuous current with sub-stations would have been, and this in spite of the fact that the continuous-current system had in any case to be adopted for the end portions of the line. The electric part of the line was executed by the Austrian Siemens-Schukert Derke in Vienna.

Supply of current. — Continuous current for operating the Vienna end section (Giselastrasse to Neu-Steinhof) is obtained from the network of the Vienna Municipal Tramways; single-phase and continuous currents for the remainder of the line are supplied from a special power station at Leesdorf.

Power Station at Leesdorf. — This is situated at a distance of 1 kilometre from the Baden end of the single-phase section. Its total capacity is at present 1,155 kilovolts-amperes, represented by one 165 kilowatt 550-volt continuous-current generator driven by a 300 horse-power vertical steam engine, one 90 kilowatt 550-volt continuous-current generator driven by a 150 horse-power horizontal compound engine, two 200 kilovolts-amperes, 10,000-volt, 15 periods alternators, each driven at 180 revolutions per minute by a direct-coupled 300 horse-power vertical steam engine, and one 500 kilovolts-amperes 10,000 volt, 15 periods alternator coupled to a 750 horse-power Lenz compound engine running at 112 revolutions per minute; this engine is supplied with superheated steam at 12 atmospheres. The boiler house equipments includes the following : six boilers, three of which have a heating surface of 80 square metres (861 square feet) each, the other three having a heating surface of 150 square metres (1,614 square feet) each for a pressure of 8 $^1/_2$ atmospheres, working without superheaters, with three Worthington feed pumps; four boilers (two of which are of the water-tube type) having a heating surface of 180 square metres (1,938 square feet) each, a superheater surface of 38 square metres (409 square feet) (suitable for superheating steam at

12 atmospheres to 300° C. [572° Fahr.]) and automatic chain-grate stokers.

The firing of the boilers and the supply of feed-water are regulated by the staff according to the time table and in such a way that the generation of steam is as far as possible in step with the fluctuations in load.

The peaks in the load are dealt with by two flywheel converters acting in conjunction with a buffer battery and automatic voltage regulators.

Each fly-wheel converter set consists of a 150 kilovolts-amperes, 10,000-volt, 15-periods alternator coupled to a 100 kilovolts, 550-volt continuous-current machine; the set rotates at a speed of 450 revolutions per minute. These sets serve as coupling between the single-phase and continuous-current portions on the Baden side; the load can be thrown on the one side or the other, as required, by adjusting the field of the continuous-current machines.

The fly-wheel effect of each set is 70,000 kilogrammetres (506,320 foot-pounds) and this assists in reducing the peak loads which occur when trains start. In order to enable the flywheels to give off a considerable portion of their stated energy, the governors of the engines driving the alternators are specially designed for a large drop in speed, so that the converter sets supply from 1,660 to 1,840 watt-hours when the speed variation ranges from 13·75 to 15·4 per cent (these being the limits of adjustment).

This energy from the converter sets is 20 per cent more than is required to accelerate a 52-ton (51·2 English tons) two coach train from standstill to 50 kilometres (31·06 miles) per hour. When the overloads are large, the accumulators on the continuous-current side are automatically made to assist.

In spite of the considerable variations in the engine speeds, the voltage is kept constant within a margin of 2·7 per cent by means of automatic voltage regulators of the Dick type.

The cost of the current at the power house works out at 9 heller (0·90 penny) per kilowatt-hour.

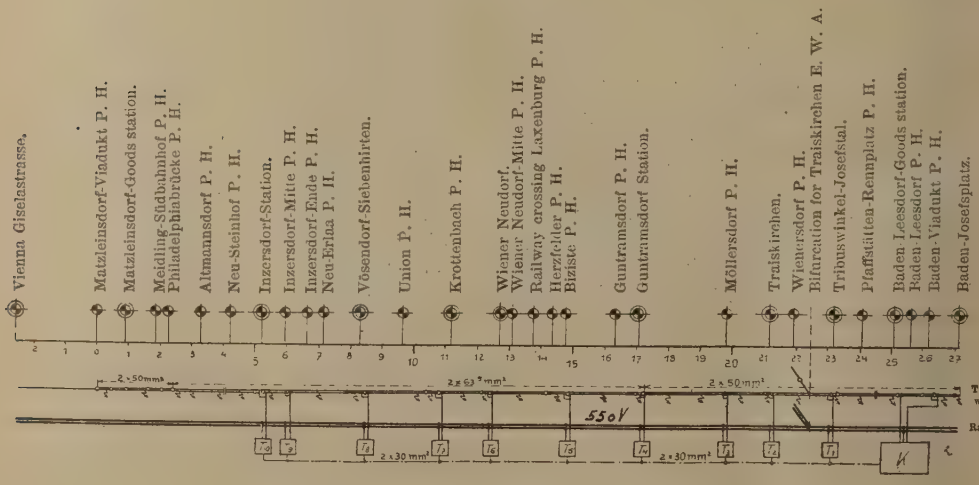


Fig. 8. — Diagrammatic plan of Vienna-Baden railway.

Fig. 9. — Motor-coaches and sub-station, Vienna-Baden Railway.

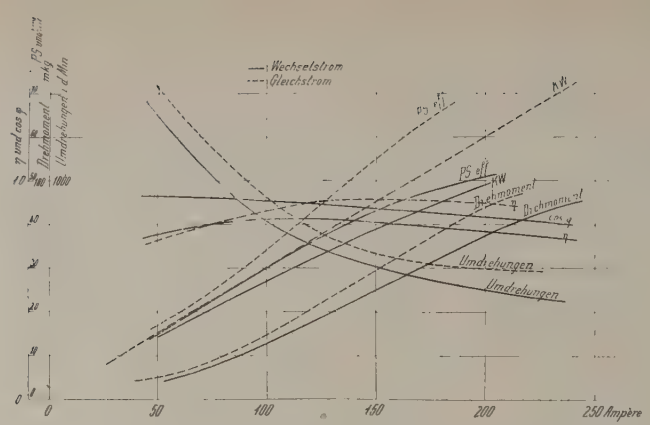


Fig. 10. — Characteristic curves of the motors (at 300 volts) used on the Vienna-Baden Railway.

Explanation of German terms : η und cos φ = Efficiency and Power factor. — Drehmoment = Torque. — P. S. und K. W. = B. H. P. and K. W. — Umdrehungen i. d. Min. = R. P. M. — Wechselstrom = Alternating current. — Gleichstrom = Continuous current. — PS eff. = B. H. P.

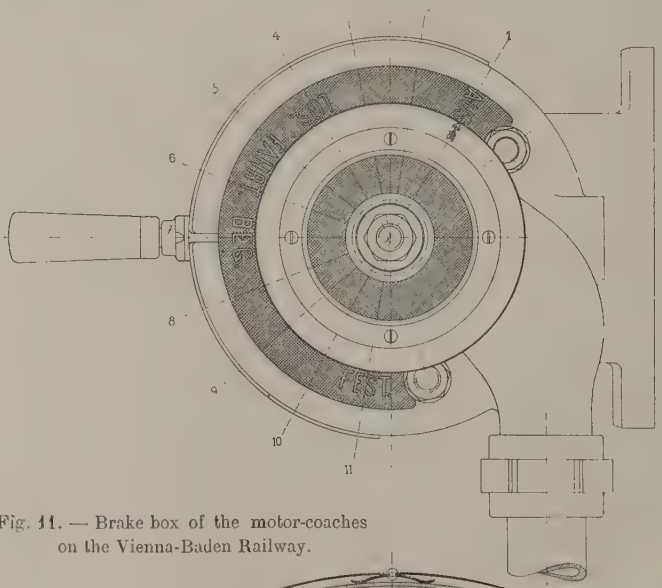
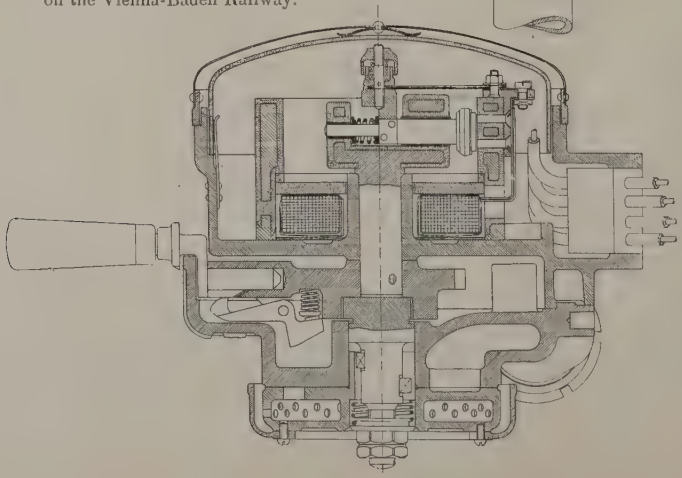


Fig. 11. — Brake box of the motor-coaches on the Vienna-Baden Railway.



Feeders. — On 20 kilometres (12·42 miles) of the single-phase portion, the feeders consist of 2 × 30 square millimetres (0·0465 square inch) soft-copper wires, carrying current at 10,000 volts. The feeders are carried on the same poles which support the overhead wires, and at a height of 7·2 metres (23 ft. 7 1/2 in.) above ground. Each insulator carries at either side an earthed ring of iron wire (see fig. 8).

Sub-Stations. — There are at present ten sub-stations, consisting of small two-storey buildings of reinforced concrete, 2 metres (6 ft. 6 3/4 in.) long by 2 metres (6 ft. 6 3/4 in.) deep, and provided with an entrance 2 metres (6 ft. 6 3/4 in.) by 0·8 metre (2 ft. 7 1/2 in.) in plan.

Each sub-station building is equipped with a 110 kilovolts-amperes 10,000/500 volt transformer on rails. The sub-stations are 3·5 kilometres (2·17 miles) apart a distance which calculations have shown to give the most economical results. A view of a sub-station is shown in figure 9.

Overhead Line. — The overhead wire is suspended at a height of 5 1/2 metres (18 ft. 1/2 in.) over rail level. It is of hard-drawn copper and has generally a cross section of 64 square millimetres (0·0992 square inch); in parts, however, the section is 2 × 45 square millimetres (0·0697 square inch), while on the oldest portion of the line the cross section is partly 50 square millimetres (0·0775 square inch). The minimum height (3·9 metres [12 ft. 9 9/16 in.) occurs where the line passes under the Südbahn.

The lattice poles, which are on a average 35 metres (114 ft. 6 in.) apart, carry double brackets of wrought iron. A " dead " section, 13 metres (42 ft. 7 13/16 in.) in length, is interposed between the single-phase and continuous-current sections. Within the Vienna area, the overhead wires of the municipal tramways are used.

On account of the large increase in traffic consequent on the introduction of electric traction, it was soon necessary to duplicate the overhead lines on certain portions and to increase the number of sub-stations from six to ten.

No appreciable disturbances occurred in the state-owned telegraph and telephone wires, which run at the side of the railway, and the service telephones were only affected when the insulation was in a poor condition.

Composition of trains. — The trains are made up of one motor coach and two or three trailers having four axles. The gross weight of a three-coach train is 62 tons (61 English tons). At present, the maximum speed is 50 kilometres (31·06 miles) per hour, but later on this is to be increased to 60 kilometres (37·28 miles) per hour.

Rolling stock. — At the end of 1907, the rolling stock consisted of fourteen motor coaches, twelve new and six old trailers. Since the opening, five old four-axle trailers have been converted to motor coaches, and fifteen light trailers have been purchased (1908).

Motor coaches. — The motor-coaches are provided two bogies, and each of the four axles is driven by a separate motor. The carriage is 13 metres (42 ft. 7 13/16 in.) long and 2·2 metres (7 ft. 2 5/8 in.) wide. The distance between the pivots of the bogies is 6 metres, and the wheel base of each bogie is 1·85 metres (6 ft. 27/32 in.), while the wheels have a diameter of 850 millimetres (2 ft. 9 1/2 in.). There is seating accommodation for forty-four passengers, while the total holding capacity is seventy-four passengers. The weight is 27·5 tons (27 English tons) (16·6 tons [16·3 English tons] for the truck, 10·5 tons [10·3 English tons] for the electric equipments and 400 kilograms [882 lb.] for the vacuum brake). The weight of a trailer is 17 tons in round figures. Figure 9 is a view of a motor coach. The mechanical portions of the coaches were supplied by the firm of F. Ringhoffer of Prague.

Current is collected by double bow collectors, the contact strips of which are always at the

*

same angle no matter at what height the bow collector is.

The motor equipment of a motor-coach comprises four single-phase geared series motors, type BME 50 of the Austrian Siemens-Schuckert Werke, with separate compensation and commutation pole windings. The motors are divided into groups of two motors each which are permanently connected in series. Each motor has six poles and is capable of developing 40 horse-power on the one hours' rating; they can be operated with single-phase or continuous current. The commutator brushes last on an average a distance of 20,000 kilometres (12,428 miles).

The speed regulation (in the case of single-phase operation) is effected by means of an auto-transformer with regulating switch. With a terminal voltage of 250 volts, a train weighing 62 tons (61·0 English tons) gross attains a speed of 40 kilometres (24·85 miles) per hour on 0·7 per cent gradient, and with a pressure of 300 volts a speed of 60 kilometres (31 miles) per hour is attained on a gradient of 0·35 per cent. Starting is performed with a pressure of 160 volts, and the further regulation is effected without interrupting the current (see fig. 10).

On the continuous-current sections, speed regulation is obtained by the familiar series-parallel control with resistances, the transformer being switched off. With a pressure of 120 volts and a train of the same weight as before, a speed of 15 kilometres (9·5 miles) per hour is attained on grooved rails on a gradient of 1·5 per cent.

The motor-coach is provided with two separate controllers. A number of interlocking devices were originally in use. For instance, when the train was on the continuous-current section or when the current was interrupted, the transformer switch was automatically locked, but released again by means of a small transformer with electro-magnet when single-phase current came on.

Another automatic device prevented too high a speed being attained on the continuous-current sections in the towns. These devices were, however, discarded later on as being unnecessary.

There are altogether eight running and six braking positions (magnetic blow-out). Multiple-unit control is not employed.

Current for lighting is obtained from the power circuit.

The signal lamps are for 65 volts, and the carriage lamps for 50 volts, and flickering is practically absent in spite of the low frequency.

A signal horn is employed (in preference to a signal bell which is not always easy to hear), being operated by the exhaust from the brake pumps (see also description of the Trient-Malè line).

The service brake is of the Hardy vacuum type; the pump is of the rotary type and is driven by a 2·5 horse-power motor. The brake motors have two commutators which are connected in series. They can be operated with single-phase or continuous current at pressures up to 500 volts and rotate at speeds up to 900 revolutions per minute. The motor starters, together with the brake levers, are mounted in cylindrical brake boxes. By suitably regulating the speed of the pump motors and the air cocks of the brake, it is possible to adjust the braking effect to a nicety (fig. 11).

The various positions marked (fig. 12) on the brake box are as follows :

In positions 0 to 6 the air-inlet remains closed, but from position 7 up to 11 the air-inlet is more and more opened, position 11 corresponding to the maximum braking effect. The motor is switched off in positions 0 (when the handle can be taken off), 1 and 11 ; in positions 2 and 6 to 10 the full resistance is connected in series with the motor which, therefore, runs at a slow speed; in positions 3 and 5 half the resistance is in series with the motor, while in position 4 the motor runs without series resistance. The braking effect is therefore dependent on the difference between the air entering through the valve and the sucking action of the vacuum pump, both of which can be adjusted to give the desired effect. The switch is provided with magnetic blow-out. The series resistance takes the form

of air-cooled brick-type resistances of nickelin.

A comparatively large amount of current is consumed by the air brake described above, but the regulation of the braking effect is exceedingly fine. Hand brakes and short-circuit brakes are provided for energencies.

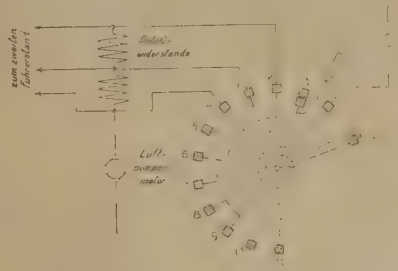


Fig. 12. — Diagram of connections of pump, motor and brake box. — Vienna-Baden railway.

Explanation of German terms : Zum zweiten Führerstand = To the second platform. — Anlasswiderstände = Starting resistances. — Luftpumpen moteur = Motor of air-pump.

Figure 13 shows the drivers platform with the two controllers, the brake-box and the air-pressure gauge.

The platforms of the motor-coaches are covered in. The drivers are enabled to clean the outside of the front windows from snow or ice (with the object of obtaining a clear view) by means of a strip of india-rubber which is worked by a suitable mechanism operated by a hand crank from the inside. At each end of the coach, there are side doors which are generally kept closed, but which enable the train staff to get from one coach to another in case of emergencies. The passage from coach to coach is facilitated by steps of corrugated iron which are fixed to the ends of the coaches and are let down into position between the cars during service.

The motor coaches were originally provided with rotating iron chairs, but as these were heavy (1 ton per motor coach) and too narrow, they were replaced by wooden seats.

The trailers ordered at the beginning were so designed that they could be converted to motor coaches by adding the necessary equipment but as this implied an unnecessarily heavy construction to begin with, the above condition is no longer imposed for new trailers.

Car shed and repair workshops. — The car shed at Matzleinsdorf has six tracks and can accommodate eighteen motor coaches ; at Leesdorf there is a shed with five tracks for fifteen motor coaches and a repair shop.

Current consumption. — Tests, extending over four hours during heavy winter traffic, showed that the electrical energy supplied to the feeders was expended as follows :

70 1/2 per cent for train haulage ;

7 per cent lost in the feeder and overhead wires ;

3·4 per cent lost in the sub-stations ;

3 per cent consumed by the brake pumps and the transformers of the automatic interlocking devices ;

12 1/2 per cent consumed for heating and lighting the coaches ;

3 1/2 per cent for station lighting.

The calculated consumption, as measured at the bow collectors, is 30 watt-hours per ton-kilometre for express trains and 55 watt-hours per ton-kilometre for passenger trains which have to start frequently. The average single-phase energy supplied by the power station on week

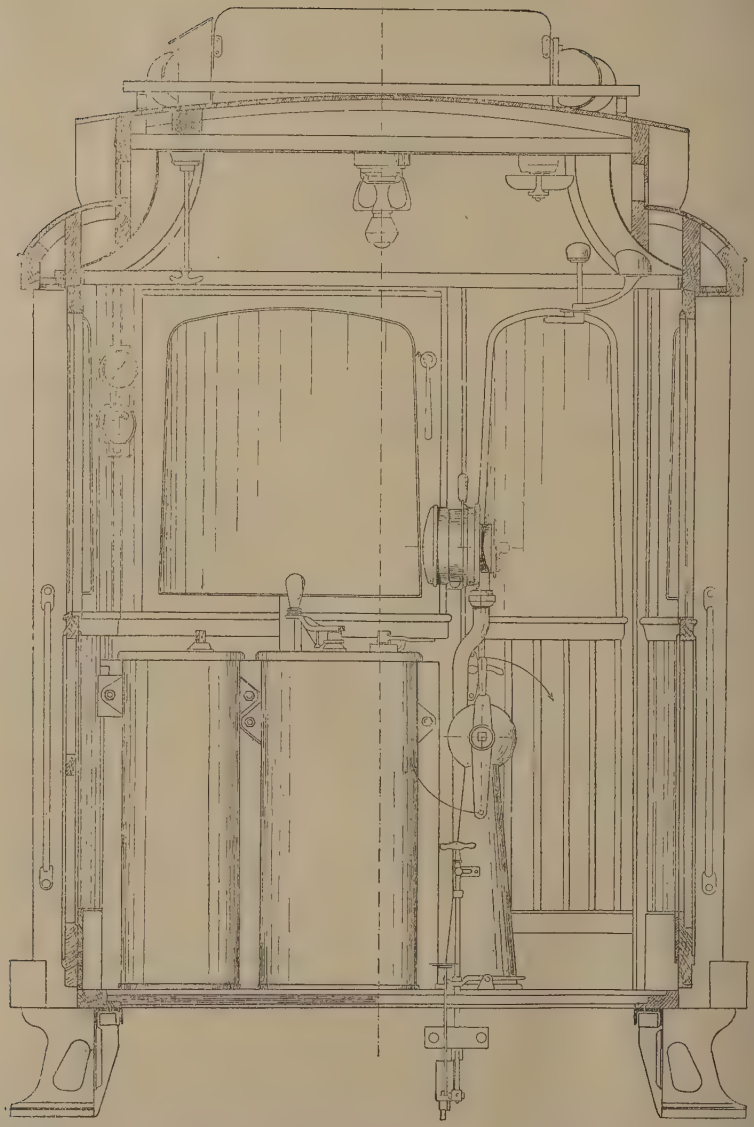


Fig. 13. — Interior view of drivers platform on the motor-coaches. Vienna-Baden Railway.

days is 450 kilowatts in summer and 300 kilowatts in winter; the maximum loads range from 1,150 to 1,200 kilowatts for single-phase and up to 450 kilowatts for continuous current; the ratio of average to maximum output is therefore anything up to 1 : 4 in the case of single-phase operation.

The yearly output of the power station is about 2,650,000 kilowatt-hours.

Service. — The winter time table 1909-1910 for electric and steam traction is shown graphically in figure 7. There are per hour at most three pairs of electric trains, express and passenger trains.

Sunday traffic is considerably heavier than weekday traffic.

The service was performed in 1909 by fifty-six regular express and passenger trains, and forty extra trains in summer and twelve extra trains in winter, in addition to the numerous goods trains hauled by steam locomotives. To this must be added the empty runs to and from the car sheds before and after working hours.

In 1908, 1,978,242 passengers and 357,857 tons (352,205 English tons) of goods (of which 172,073 tons [169,355 English tons] were transit goods) were carried, corresponding (as regards the passenger traffic) to 814,641 train-kilometres (506,203 train-miles), 1,469,544 car-kilometres (913,148 car-miles) and 5,878,176 axle-kilometres (3,652,593 axle-miles), and as regards the steam-operated goods traffic to 129,077 train-kilometres (80,206 train-miles), 620,166 wagon-kilometres (385,360 wagon-miles) and 1,240,332 wagon axle-kilometres (770,720 wagon axle-miles).

Running costs and capital expenditure. — The running costs (in kronen) during 1908 were as follows :

—	Passenger service (electric), in kronen.	Goods service (steam), in kronen.
General administration.	38,642	21,898
Railway supervision and maintenance.	214,054	55,585
Train haulage (including cost of current).	296,192	107,258
General service expenses	232,234	101,013
Miscellaneous working expenses	66,484	23,964
Total. . .	847,606	309,718

The receipts from passenger traffic amounted to 1,247,179 kronen (£51,882.13*s.*) from goods traffic to 367,602 kronen (£15,292.5*s.*) (of which 198,086 kronen [£8,240.8*s.*] were for goods in transit). The ratio was therefore 68 per cent as regards the passenger service and 84·3 per cent as regards the goods traffic, and 71·6 per cent for the service as a whole. The running costs proper were 62·7 per cent of the receipts in the case of electric traction, 77·7 per cent in the case of steam traction, and 66·2 per cent for both combined. The net profit, amounting to 315,953 kronen (£13,143.13*s.*), permitted the payment of a 4 per cent dividend.

In the first year of electric passenger traffic the receipts increased by 180 per cent.

The *total expenditure* for the conversion to electric traction, which was carried out during 1906, 1907 and 1908, including work on the permanent way, buildings etc., amounted to

6 million kronen (£249,600); of this sum, 3 million kronen (£124,800) were expended on the mechanical and electrical equipment, including rolling stock, car sheds, power station and sub-station buildings and alterations to the state-owned telephone and telegraph lines.

Bruneck-Sand in the Tyrol (Taufcrer railway).

This railway was opened on the 21st of July 1908. It is a full-gauge, single-track local line, 15·24 kilometres (9·47 miles) long, with a maximum gradient of 1·8 per cent and a sharpest curve of 150 metres (7 1/2 chains) radius; 78 per cent of the total length lies in gradients. Continuous-current at 750 volts is used. The rolling stock consists of two motor-coaches (each of which is driven by two 65 horse-power motors) and two trailers. From the date of the opening until the end of 1908, 1,581 trains were run, corresponding to 23,719 motor-car-kilometres (14,739 motor car-miles) and 578,331 gross ton-kilometres (365,131 English ton-miles). The daily service is maintained by three pairs of regular trains, one pair of extra trains and one pair of mixed trains.

Neumarkt-Kallham-Waizenkirchen and Niederspaching-Peuerbach.

This full-gauge, single-track local railway, which was opened on the 18th December 1908, leads from Neumarkt-Kallham to Waizenkirchen and a branch line runs from the intermediate station of Niederspaching to Peuerbach. There are ten stopping places. The sections measure 12·7 and 3·6 kilometres (7·9 and 2·2 miles) in length respectively, the total length being 16·29 kilometres (10·12 miles). The maximum gradient on the main section is 1 per cent for a length of 1·45 kilometre (0·90 mile); the maximum gradient on the branch line is 1·6 per cent. The sharpest curves have a radius of 200 metres (10 chains). The maximum permissible weight per axle is 10 tons (9·8 English tons). The line is composed entirely of up and down gradients.

The rolling stock comprises three motor-coaches (of which one is kept in reserve with two axles and two 54 horse-power motors, short-circuit brake, wheel base 4·8 metres (15 ft. 9 in.); weight empty 15 tons (14·7 English tons), fully loaded 19 1/2 tons (19·2 English tons).

The trailers are equipped with solenoid brakes, wheel base 4·8 metres (15 ft. 9 in.); weight empty 6 tons (5·1 English tons), fully loaded 9 tons (8·8 English tons).

The goods wagons are covered in and provided with hand brakes only; wheel base 4·1 metres (13 ft. 5 1/2 in.); weight empty 5·77 tons (5·67 English tons), fully loaded 12·9 tons (12·7 English tons).

All passenger cars are heated and lighted by electricity.

The maximum speed is 30 kilometres (18·6 miles) per hour.

Current is obtained from the sub-station at Niederspaching, which is equipped with two 50 kilowatt converters and a battery for 750 volts. In normal service, when two trains at most are running at the same time, the power station has an output of 165 kilowatts, but overloads up to 195 kilowatts can be dealt with for one hour.

The largest train weight for passenger and mixed trains is 40 tons (39·3 English tons), and for the slower running goods trains 80 tons (78·6 English tons).

In the summer of 1909 the service on the main section was performed by five pairs of regular trains and two pairs of extra trains, and on the branch line there were ten pairs of regular trains and three pairs of extra trains. The energy consumption amounts to about 100,000 kilowatt-hours per annum.

Brunn Tramways (goods locomotives) (1).

A short time ago, three electric locomotives were obtained for hauling goods trains on the

(1) F. Gubler, « Die elektrischen Lokomotiven der Brünner Strassenbahn », published in *Elektrotechnik und Maschinenbau*, 1909, p. 967.

electric tramway system in and around Brunn. The locomotives, which are fed with current from the 500-volt overhead wire, are provided with four driving axles; they weigh 21 tons (20·6 English tons) without ballast and 28 tons (27·5 English tons) when fully loaded with ballast. They are designed for hauling a normal load of 100 tons (98·4 English tons) on a 2·6 per cent gradient and are intended to haul passenger carriages in exceptional cases.

Each locomotive is equipped with four 42 horse-power series motors with commutation poles, arranged in two groups of two motors each; the two motors of each group are permanently connected in parallel. The power is transmitted to the driving wheels (900 millimetres diameter [2 ft. 11 $^{7}/_{16}$ in.]) by gearing as in tramway practice, the gear ratio being 1 : 6·06. The speed is 8 $^{1}/_{2}$ kilometres (5·3 miles) per hour at full load and full excitation, and can be increased to 14 kilometres (8·7 miles) per hour by weakening the motor fields.

The series-parallel controller has fourteen running positions, of which six are economical running positions obtained by weakening the motor fields. This is an important advantage for shunting operations and is rendered possible chiefly by the provision of commutation poles (compare the similar arrangement adopted for the motor coaches on the Trient-Malè line).

When the locomotives are used for hauling passenger trains (the trailers of which are not equipped with air brakes), the first seven steps of the controller can be used for a short-circuit brake. The controller handle is provided with a press button which must be pressed down by the driver during the journey. This device, borrowed from American railway practice, is advisable as the locomotive is handled by one man only and does not run on its own separate track. Should this button be released at any time during running, the motors are automatically switched off and the air brakes applied. The time which elapses from the moment when the motors are switched off until braking commences is about two seconds, but it can be regulated by an air dash pot.

The goods trains are provided with short-circuit brakes, standard hand brakes and compressed-air brakes. The air compressor is driven by an electric motor. Compressed air is also used for sanding purposes and to actuate a whistle and a signal bell. A foot-operated signal bell is also provided. The compressed-air signal bell is operated as follows : The bell hammer is fixed to the piston of the air cylinder, and both are caused to swing and to strike against the bell by the compressed air; at the end of the stroke the air is allowed to escape from the cylinder, and the piston with bell hammer attached is withdrawn by spring action. This cycle repeats itself, and a loud signal is obtained with a small consumption of compressed air.

Two devices are employed for collecting the current, viz. the ordinary tramway trolley and (for shunting operations) a pantograph collector with cylindrical contact roller. These two collectors are so arranged that only one of them can be used of a time.

In order to ensure safety under all conditions, two circuit-breakers with overload release are provided in series. An auxiliary circuit is connected across the motors, its path being as follows : Starting from one side of the motor, the circuit passes through a hand-operated emergency switch to the contacts of the double overload release, then through the locking contacts and the magnet coils of the circuit-breaker and finally through the contacts of the safety button in the controller handle (see above) back to the other side of the motor. This electrical interlocking has the effect that the circuit-breaker can only be closed when the controller is in the "off" position. Each locomotive has only a single controller, mounted in the centre of the driver's cab.

The electrical equipment of the locomotives was supplied by the A. E. G.-Union Company of Vienna.

Trient-Malè (Nonstal Railway) (1).

Characteristic features. — This local railway, which is 59·6 kilometres (37·0 miles) long and has a gauge of 1 metre (3 ft. 3 3/8 in), has to deal with comparatively heavy passenger and goods trains. Current is obtained from the three-phase Sarca power station belonging to the town of Trient. The supply pressure is 20,000 volts. There are three converter sub-stations, the equipment of which includes buffer batteries and Pirani boosters. The highest continuous current voltage is 840 volts. Speed regulation is obtained by weakening the motor fields; short-circuit brakes. Signal horns operated by the exhaust from the vacuum pumps. Maximum gradient, 5·3 per cent; the sharpest curves have a radius of 28 metres (1 4/10 chains). There are altogether forty-two stopping places, of which ten are fair-sized stations.

General notes on the railway. — The railway is single-track throughout; it is 59·6 kilometres (37·0 miles) long and has a gauge of 1 metre (3 ft. 3 3/8 in.). The gradients range up to 5·3 per cent and the curves have radii down to 35 metres (1 3/4 chains) and in one instance only 28 metres (1 4/10 chains). The line runs through a number of localities, in the larger ones of which it also serves for local transit. In some cases the line passes between houses which are so near together as to leave barely sufficient clearance. The slow speeds necessary at these points and the continual change in the gradients render an economical speed regulation important. A map of the line is shown in figure 14.

The rails are alternately of the round-headed type weighing 21·8 kilograms per metre (43·9 lb. per yard) and partly 26 kilograms per metre (52·4 lb. per yard) laid on a separate track and of grooved pattern (in the localities traversed) weighing 35 kilograms per metre (70·5 lb. per yard).

Electric traction was planned from the very start. The power station on the Sarca, as well as the sub-stations and high-tension transmission lines, are worked by the municipality of Trient. The same power station also supplies the current for the town. The railway installation, commencing with the continuous-current lines from the three converter sub-stations, is managed by the Austrian State Railway Administration.

According to calculations made at the time when the system of traction was under discussion, steam traction would have been much less economical than electric traction on account of the steep gradients and the high cost of coal.

Three-phase feeders. — Three-phase current at 20,000 volts and 50 cycles per second is conveyed to the three converter sub-stations by three copper wires, having a cross-section of 25 square millimetres (0·0387 square inch) each as far as Sabino, and of 20 square millimetres (0·031 square inch) from Sabino to Mostizzolo. The wires are carried on lattice poles, spaced at distances from 80 to 100 metres (262 ft. 6 in. to 328 feet) (in one place 170 metres [557 ft. 8 in.]). Every 8th pole is in the form of a double-T pole (see fig. 15) so as to enable it to "give" in the case of a breakage of wires.

Converter sub-stations. — In the three sub-stations, which are situated at Pressano, Sabino and Mostizzolo, the three-phase current is converted to continuous current at a pressure of 800 volts with a margin of 5 per cent up or down. Each sub-station is equipped with two 130 kilowatt converters and a battery for 800 volts and 148 ampere-hours on the 1 hours' discharge (the maximum current is 222 amperes).

The maximum current required for the railway is about 1,300 amperes (or approximately 1,000 kilowatts at the feeding points); this

(1) « Die Lokalbahn Trient-Malè und die neuen Elektrizitätswerkanlagen der Stadtgemeinde Trient », by Baurat Ingenieur Paul Dittes, now being published in the *Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines*, 1910, nos 4 and 5. (As regards the Pirani system of boosting, see *Elektrische Kraftbetriebe und Bahnen*, 1908, No. 9.)

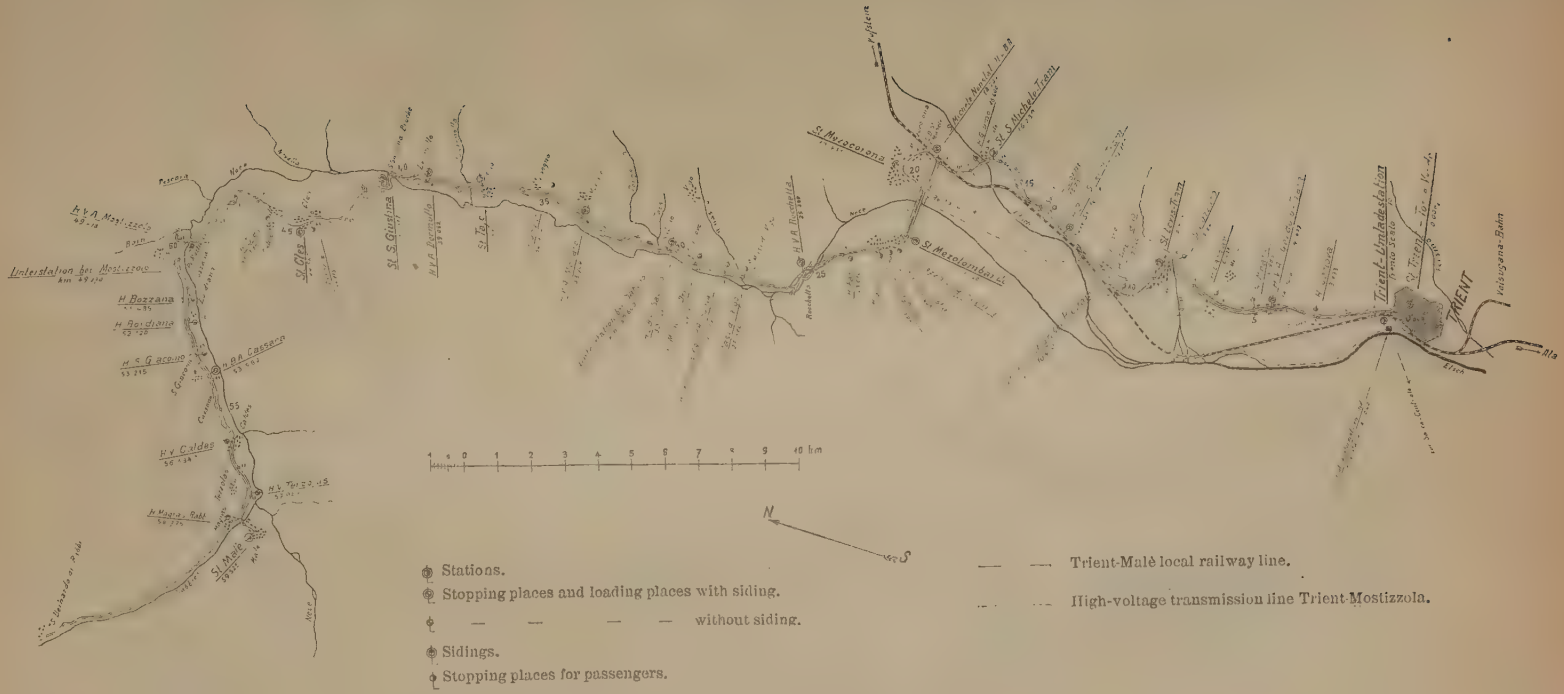
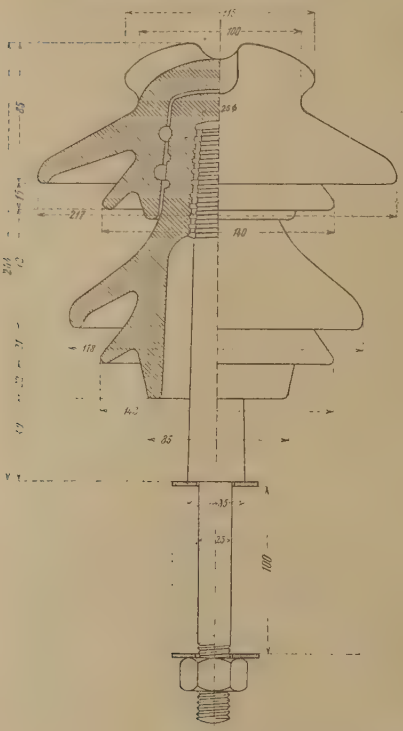


Fig. 14. — Plan of Trient-Malè Railway.

Transmission line Dro-Trient.



Transmission line Trient-Mostizzolo.

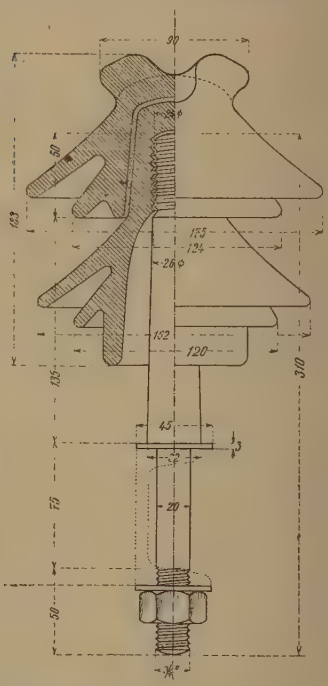


Fig. 15. — 20,000 volt insulators on the Trient-Malè line.

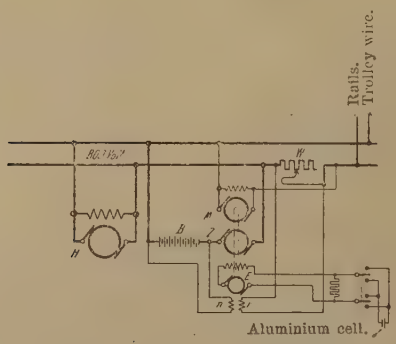


Fig. 16. — Diagram of connections of the Pirani installation, Trient-Malè railway.

demand can be supplied by one converter, working at 40 per cent overload, and battery at each sub-station. Pirani boosters are provided to regulate the buffer action of the batteries (see fig. 16). The Pirani machines, for which the Siemens-Schuckert Werke have obtained the patents, are employed in the sub-stations for two reasons, viz. to steady the load on the main generators, and to keep the bus-bar voltage as constant as possible. In figure 16, H denotes a railway generator, B the battery, which is connected in parallel with the generators, M a shunt motor, Z the Pirani booster, E the exciter of the Pirani booster, n and r the shunt and series windings of the exciter and W a series resistance. The interaction of the various machines is as follows.

When the load on the station is nil, no current passes through the series winding r, but the shunt n is excited in such a manner that the exciter E produces in Z a voltage of such polarity and intensity that the battery is heavily charged by the main generators H.

When the load comes on, the series winding r partly neutralises the shunt winding n, in consequence of which the battery B is less heavily charged and the generators H are thus enabled to supply a corresponding amount of current to the network. As the voltage of the battery B drops, the shunt n is further weakened and the re-action on the booster Z etc. is accentuated.

At a certain station load, the windings r and n neutralise one another completely; the booster Z has then no terminal voltage and the battery B is neither charged not discharged.

When the load increases beyond this point, the winding r, in conjunction with the exciter E, produces at the terminals of the booster Z a voltage of opposite polarity to that which obtained before, and the battery B is heavily discharged, thus strongly assisting the main generators H. As the voltage of B drops, this action is again accentuated.

Figure 17 is a graphic representation of the various auxiliary voltages.

In practice, it has been found desirable to be able to obtain different values for the boosting voltage (for one and the same exciter voltage E) according to whether the magnetisation acts in the one sense or the other, and for this purpose an aluminium cell with resistance in parallel is inserted in the exciter circuit (see fig. 16). In one direction, the current flows mainly through the cell, but in the other direction mainly through the resitance, and is then of course weaker than before. By means of change-over switch, this unequal action can be made to operate in one sense or the other, so that it is possible either to increase the charging or discharging current of the battery. The characteristic curve of the boosting voltage can therefore be made steeper or flatter than shown in figure 17.

The characteristic curve of the boosting voltage can also be wholly shifted towards the left or the right by adjusting the shunt resistance of the booster Z. It can also be rotated by regulating the series resistance B. It is, therefore, possible to obtain any desired buffer-action of the battery B by suitably adjusting these various resistances. By experimenting with various combinations, a combination can always be found which will give an exceptionnally powerful buffer-action suitable for an exceptional case (Sunday traffic, etc.).

In the present case the decision to provide a boosting installation was largely influenced by the desire to keep the load as constant as possible, having regard to the fact that the high-tension lines also supply lighting current for the town of Trient.

Figures 18 and 19 show the sub-stations in plan and section.

Continuous current feeders. — On six lengths of the line, the overhead wires are strengthened by the addition of one copper wire (in one place two wires) of 50 square millimetres (0·0775 square inch) cross-section. In several places in thickly populated localities these had to be dispensed with, although otherwise desirable.

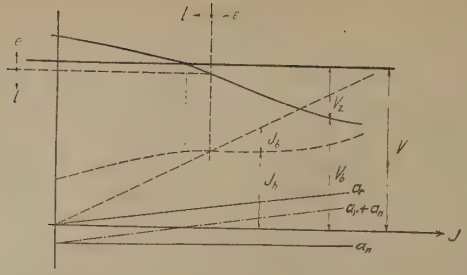


Fig. 17. — Characteristic curves of voltages and currents in Pirani installation.

I and J = Current; V = Terminal voltages (the figures with suffix refer to the battery and machines, those without suffix relate to the network); *e*, *l* = Discharge and charge of battery; *a* = Ampere-turns of machine E. To simplify matters, the assumptions have been made that the terminal voltage of the main generator H = Voltage in the network, and that both are constant.

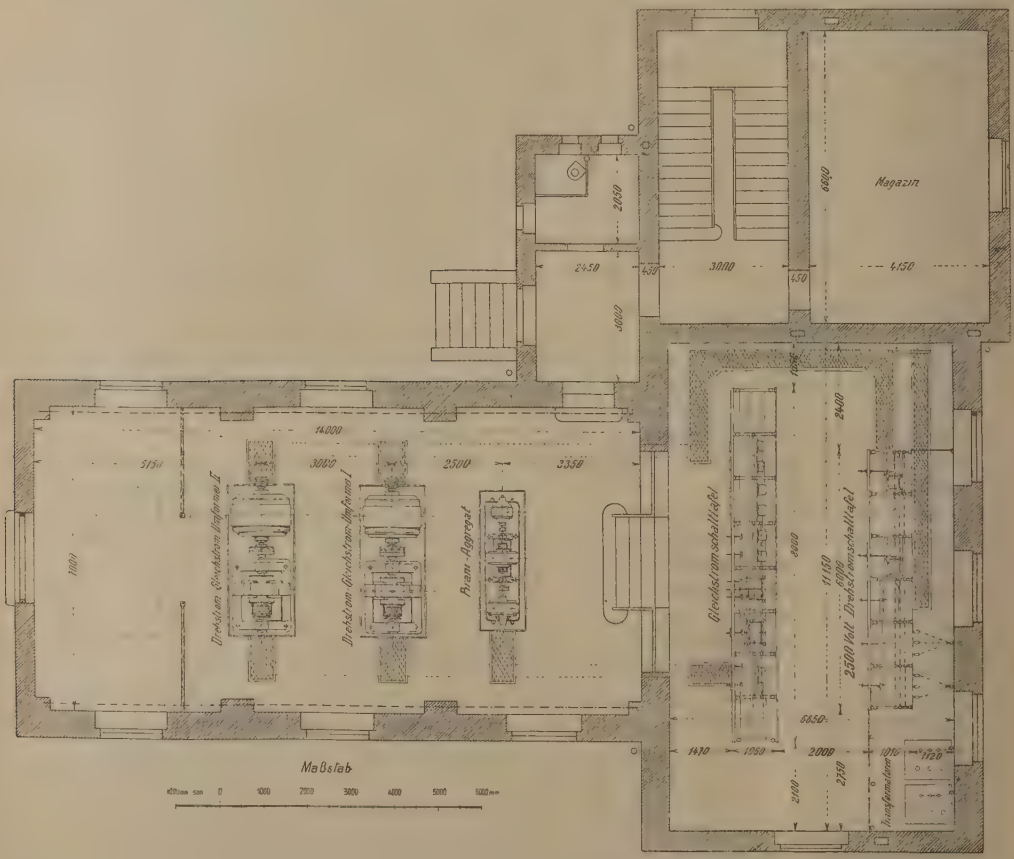


Fig. 18. — Plan of sub station. — Trient-Malè Railway.

Explanation of German terms: Masstab = Scale. — Drehstrom-Gleichstrom-Umformer = Motor-generator (three phase-continuous current). — Pirani-Aggregat = Pirani-Set. — Gleichstromschalttafel = Continuous-current switchboard. — 2,500 Volt Drehstromschalttafel = 2,500 volt three phase switchboard. — Magazin = Store. — Transformatoren = Transformer.

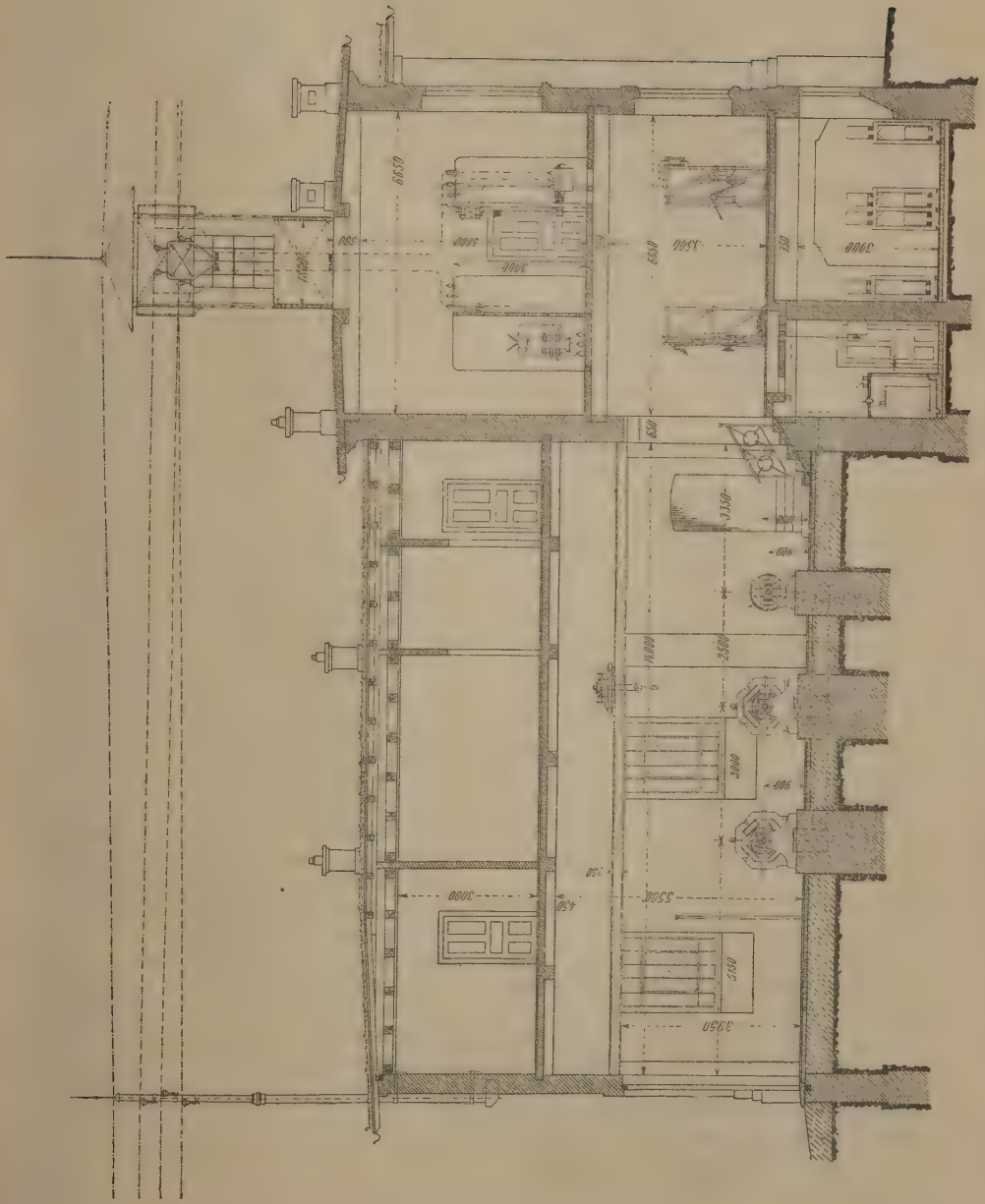


Fig. 19. — Section through sub-station. Trient-Malè Railway.

Overhead wires. — The overhead line over the whole length of the railway consists of double wires of head-drawn copper, of grooved section, the cross-section being 2 × 70 square millimetres (0.1085 square inch). The poles, of larch wood, have a diameter of 28 centimetres (11 inches) at the bottom, tapering to 18 centimetres (7 inches) at the top; their length varied from 9·2 to 10 metres (29 ft. 11 in. to 32 ft. 10 in.). The clear distance between the poles and the centre of the track is at least 1,900 millimetres (6 ft. 2 3/4 in.) on straight stretches, and in curves this distance in increased as follows :

Radius of curve, in metres.	On the outside.	On the inside.
500	1,915 (1940)	1,930 (1925)
200	1,930 (2010)	1,975 (1970)
100	1,965 (2115)	2,045 (2040)
40	2,060 (2305)	2,270 (2255)
35	2,080	2,320

The bracketed figures relate to round-headed rails and those outside the brackets to grooved rails. In the latter case the outer rails were not superelevated and this is the explanation of the differences in the figures. The insulation resistance of the double overhead lines was guaranteed by the contractors to be not less than 5,000 ohms per kilometre (8,047 ohms per mile) in rainy weather and at the full service voltage; this guarantee was substantially exceeded. The resistance of the return path for the current through the rails, taken as the average of ten different tests, was guaranteed not to exceed 0·045 ohm per kilometre (0·072 ohm per mile); the actual resistance was found to be less.

Motor-coaches. — At present, there are ten two bogie motor coaches, of which eight or nine are in service, while one is kept in reserve. They are used for passenger traffic and for the postal and parcel service, as well as for the haulage of goods wagons (see fig. 20). The electrical equipment of the entire rolling stock was supplied by the A.E.G.-Union C°, while the mechanical portion of the coaches was supplied by the Grazer Waggon- und Maschinenfabrik in Graz. Each of the two American bogies with pressed steel frames is provided with two motors (see fig. 21 and 22).

The weight of an empty motor coach is 21 tons (20·6 English tons) (14·3 tons [14·0 English tons] for the mechanical portion and 6·7 [6·6 English tons] for the electrical equipment).

Max. weight per axle 6·38 tons (6·28 English tons). Total length over the buffers 13 1/2 metres (44 ft. 3 1/2 in.).

The carriage is 9 85 (32 ft. 4 in.) long by 2·55 metres (8 ft. 4 9/16 in.) deep. The distance between the pivots of the bogies is 6·7 metres. The total wheel base is 8·7 metres (28 ft. 6 1/2 in.) while the wheel base of each bogie is 2 metres (6 ft. 6 3/4 in.). The diameter of the axle in the wheel hub is 125 millimetres (4 29/32 inches); the journal is 75 millimetres (3 inches) in diameter and 135 millimetres (5 5/16) long.

Each motor coach has seating accomodation for twelve first-class passengers and twenty-four third-class passengers, in addition to standing room for eight third-class passengers; there are also a luggage compartment 2 metres (6 ft. 6 3/4 in.) long and a water closet, the floor space occupied by these two compartments being 6·36 square metres (68·43 square feet).

The draw-bar is central and 700 millimetres

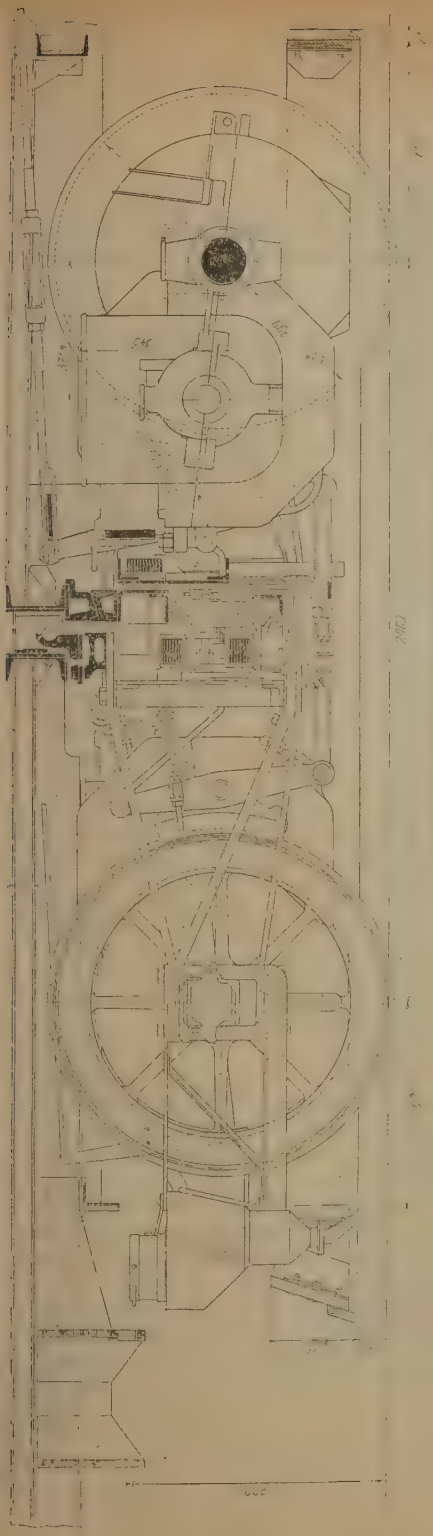


Fig. 21. — Side view of bogie of motor coach. Trient-Malè Railway.

(2 ft. 3 $^{9}/_{16}$ in.) above rail level. The platforms are open at the sides, but closed in front by a balanced middle window. The cost of a motor coach amounted to 48,000 kronen (£1,996.16*s.*) (corresponding to 2·28 kronen per kilogram of the tare (10·33*d.* per lb.) empty).

The maximum weight of a train composed of one motor coach and two trailers is 48 tons (47·2 English tons). The maximum normal speed on straight level stretches is 35 kilometres (21·7 miles) per hour; the acceleration is 0·15 metre (5 $^{29}/_{32}$ inches) per second per second.

Each of the four axles of a motor-coach is driven by its motor through gearing of 1 : 5·29 ratio. Special attention was paid to simplicity of the motor suspension gear and to accessibility of the motors (through traps in the car floor). The motor can be easily dismantled in the car pit.

The series motors (figs. 23 and 24), of the U 105 type, have four main poles and four commutation poles; the split frame is of cast steel. The armature has 37 shots; the air gap is 3 millimetres ($^{1}/_{8}$ inch). The armature is cooled by ventilating ducts. Each motor is capable of developing 44 horse-power on the one hours' rating when fully excited; its speed is then 670 revolutions per minute and the tractive effort 580 kilograms (1,279 lb.). When the field is weakened to 67 per cent of its full value, the speed is 680 revolutions per minute, the output is 66 horse-power at the periphery of the wheels (850 millimetres [2 ft. 9 $^{1}/_{2}$ in.] in diameter), and the tractive effort is 860 kilograms (1,896 lb.). The continuous rating is 18 horse-power, and motor complete with gearing and gear case weighs 1,300 kilograms (2,866 lb.) (24 $^{1}/_{2}$ kilograms [54 lb.] per 1 horse-power on the one hours' rating.

The two motors of each bogie form one group and are permanently connected in

parallel. Each group can be separately switched off, if necessity arises. The speed regulation is effected by connecting the two groups in series or parallel, in combination with field regulation by shunt resistances. The relation between tractive effort and speed after cutting out the series resistances is shown graphically in figure 25.

The controller has six running positions and seven braking positions. Before the electric short-circuit brake can be set in action, a special change-over handle must be operated, and after this has been done, the main controller handle is moved over the same contacts as in ordinary running. A special reserve handle is provided for reversing the direction of travel. No attempts have been made at regenerative control.

The service brake is an automatic vacuum brake of the Hardy type. The vacuum pump is driven by a motor rotating at speeds up to 900 revolutions per minute. The control gear for the pump motor and the vacuum brake is mounted in a compact brake box.

The design is the same as used on the Vienna-Baden line, described on a previous page. A notable feature is the high voltage (800 volts) in the switch box.

The auxiliary brakes are represented by the hand-operated balanced wheel brakes (eight brake shoes) and the electric short-circuit brake. In order to ensure equal braking of all the motors of a coach, the armatures and fields of the motors are connected up, when the electric brake is in operation, in a special manner patented by the A. E. G.-Union Company. In this method (known as the "cross-connection" method) the armatures of the two motors of one group are connected in series with the fields of the two motors in the other group. Any tendency of one group of motors to have a reduced braking effect, by reason of the armature current in this group being below normal, is neutralised by the motor fields of the group in question being very strongly energised by the heavy current from the armatures of the second group.

Each motor-coach is equipped with two bow collectors which can be shortened in telescopic fashion. All wires in the car are insulated with india-rubber and are drawn through hemp hoses lined inside with india-rubber. The incandescent lamps in the coaches are rendered safe by a suitable protection against high tension. The exterior lighting is effected by projectors, each of which has two 16 candle-power lamps, and by signal lamps. Each of the two lamps of the projectors is supplied from a different circuit. Candles are provided for emergencies. All passenger cars are heated by electric radiators.

The signalling equipment comprises bells operated by cords, electric bells and pneumatically-operated horns. The latter are worked by the exhaust from the vacuum pumps, as in the case of the motors coaches on the Vienna-Baden railway. They are set in action by the driver depressing a foot lever. This has the effect of reversing the double valve in the suction and pressure pipes of the brake pump. In consequence, the suction pipe is shut off from the main brake piping and connected instead with the atmosphere, so that a considerably larger volume of air is sucked in. At the same time, the air thus drawn in cannot escape as usual directly into the atmosphere, but is pressed through the horns, which emit a very lood sound. The vacuum pump is continuously running during the journey.

Passenger trailer cars. — There are twelve passenger trailer cars with nine seats for first class passengers, twenty three seats for second class passengers and standing room for twelve third class passengers. Weight (empty) 7 tons, maximum total weight 10·57 tons (10·40 English tons). These trailers are equipped with vacuum brake, hand brake and electric solenoid brake.

Other rolling stock. — The rolling stock also comprises 12 covered goods wagons net weight 4·42 tons (4·35 English tons), loading capacity 6 tons (5·9 English tons), wheel base 2·5 metres

Fig. 20. — Motor coach. Trient-Malè Railway.

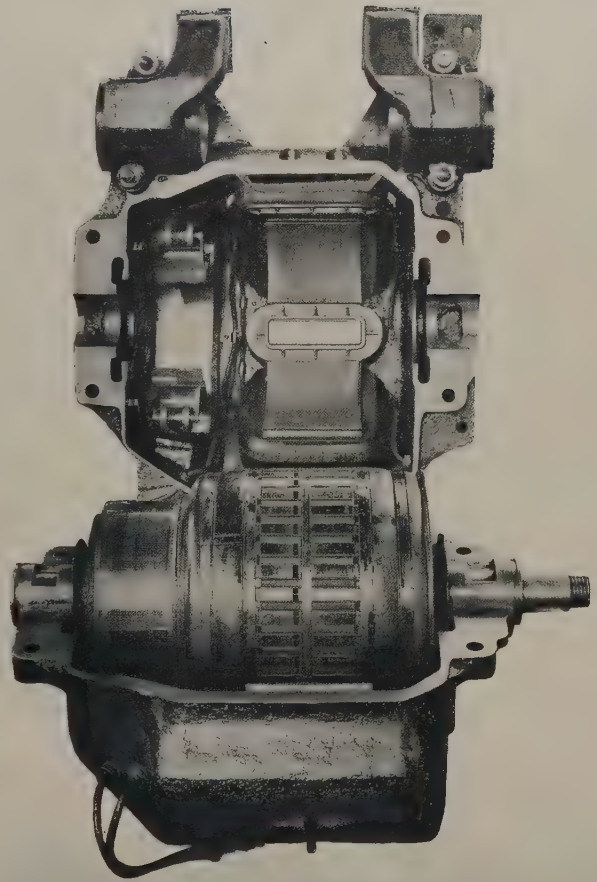


Fig. 23. — Motor, open. Trient-Malè Railway.

Fig. 24. — Motor, closed. Trient-Malè Railway.

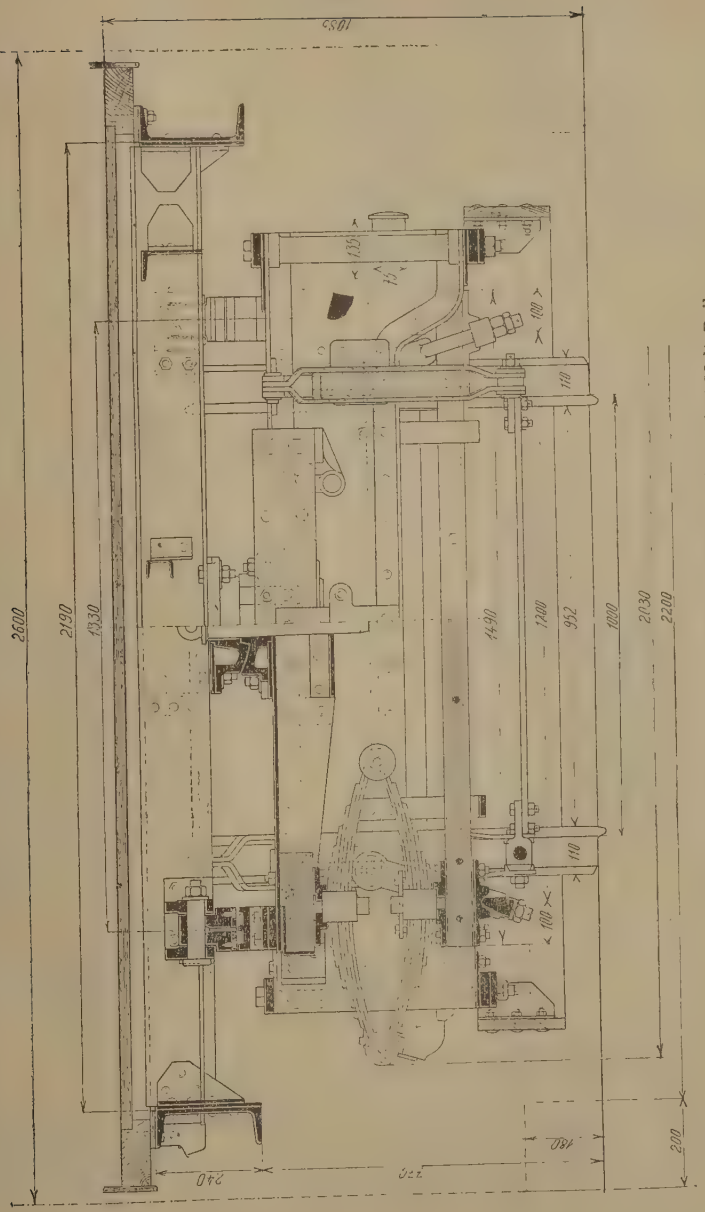


Fig. 22. — Section through bogie of motor coach. Trient-Malè Railway.

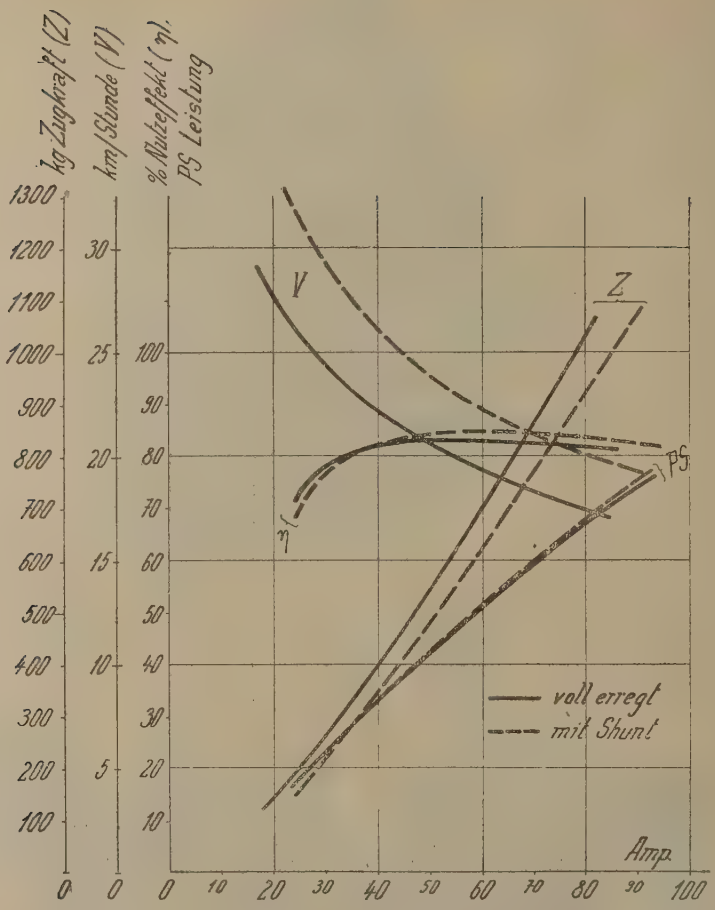


Fig. 25. — Characteristic curves of motor Trient-Malè Railway.

Explanation of German terms: Zugkraft = Tractive effort. — km/Stunde = km. per hour. — Nutzeffekt = Efficiency. — PS Leistung = Output in H. P. — Voll erregt = Fully excited. — Mit Shunt = With shunt resistance across the fields.

(8 ft. 2 ½ in.), overall length 5·51 metres (18 ft. 1 in.), floor area 9·5 square metres (102·2 square feet); 5 open goods wagons (net weight 3·7 tons (3·64 English tons) loading capacity 6 tons (5·9 English tons), wheel base 2·5 metres (8 ft. 2 ½ in.) overall length 5·16 metres (16 ft. 11 in.) floor area 9·4 square metres (101·1 square feet); 10 open goods wagons for the transport of wood (net weight 4·05 tons [3·98 English tons], other data as above); 3 post vans (net weight 6·1 tons [6·0 English tons] loading capacity 2 tons

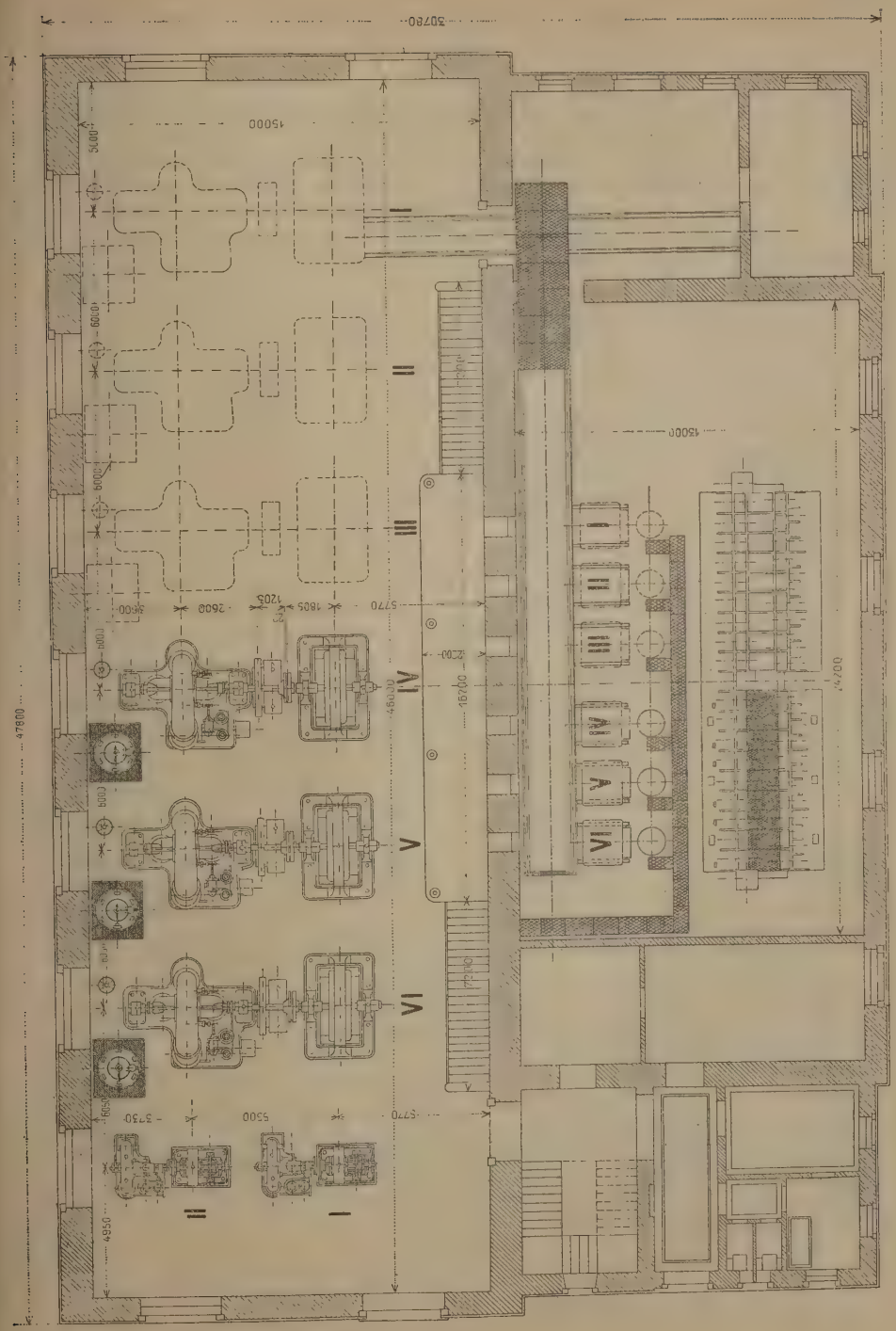


Fig. 26. — Plan of power station on the river Sarca. Trient-Malè Railway.

[1·96 English tons], wheel base 3·8 metres [12 ft. 5 5/8 in.] overall length 6·85 metres [22 ft. 6 in.] and two repair cars with raised platforms. All these wagons have two radial axles.

Capital expenditure. — The total capital expenditure of the railway, including the continuous-current feeders and overhead wires, but excluding the high-tension lines, the three sub-stations, the wayleaves to the house and land owners for permission to erect the poles and overhead wires and the expenditure involved in altering existing telephone and telegraph lines, was in round figures as follows :

Continuous-current feeders and overhead wires	950,000 kronen	(£39,520).
Rolling stock (10 motor coaches, 14 other vehicles)	868,000 —	(£36,109).
Electric equipment of work shop, electric lighting installations of stations	40,000 —	(£1,664).
Double-wire service telephone	120,000 —	(£4,992).
Total. . .	1,978,000 kronen	(£82,285).

The railway was opened for service on the 12 October, 1909. An electric motor car will have to be shortly acquired to cope with the increasing goods traffic.

The Sarca power station. — This up-to-date power station, the architecture of which is in harmony with the surrounding country, belongs to the town of Trient, and supplies, in addition to the current for the railway, current for power and lighting in and around Trient. The weir is situated at Alle Sarche and the lake of Cavedine is used as a natural reservoir. The water (from 10 to 18 cubic metres [353 to 636 cubic feet] per second) is conducted through a tunnel and a canal to six water chambers. So far, three main pipes (650 millimetres [2 ft. 1 5/8 in.] in diameter) and one pipe for the exciters have been laid. The effective head is 52 metres (170 ft. 7 in.). The total available power will amount to 9,000 horse-power when the installation is completed.

At present there are three 1,500 horse-power three phase alternators and two 200 horse-power exciters. They supply three-phase current at 5,000 volts and 50 cycles per second. The voltage is raised to 20,000 volts by portable water-cooled transformers. The current is conveyed through selector switches to two closed bus-bar mains for railway and power respectively. The main change-over switches are worked by motors. All the bus-bar and high-tension apparatus are mounted in cells of reinforced concrete.

The high-tension current is transmitted over a distance of 23 kilometres (14·3 miles) to the Padergnione sub-station by two lines, each consisting of three 50 square millimetre (0·0775 square inch) wires carried on lattice poles. Suitable apparatus is provided for switching the current on to one or the other line. The transmission lines are protected by lightning arresters. In the main transformer sub-station in Trient, the current for lighting is reduced to 5,000 volts. The current for the railway is transmitted to the three converter sub-stations.

The agreement with the town of Trient provides, for the present, for a supply of 400 kilowatts, measured at the continuous-current bus-bars of the converter sub-stations. The price of the current was fixed at 12 heller (1·20*d.*) per kilowatt-hour for a demand up to 300,000 kilowatts-hours, 5·35 heller (0·534*d.*) for further demands up to 150,000 kilowatts-hours, and 4 heller (0·40*d.*) per kilowatt-hour for any additional demand. The railway also pays to the supply authority the interest on the capital expended on, and the maintenance costs of the converter sub-stations, the equipment of which was paid for by the town of Trient, while the building and the compensation to land owners were paid for by the railway.

Figures 26 and 27 show the lay out of the power station.

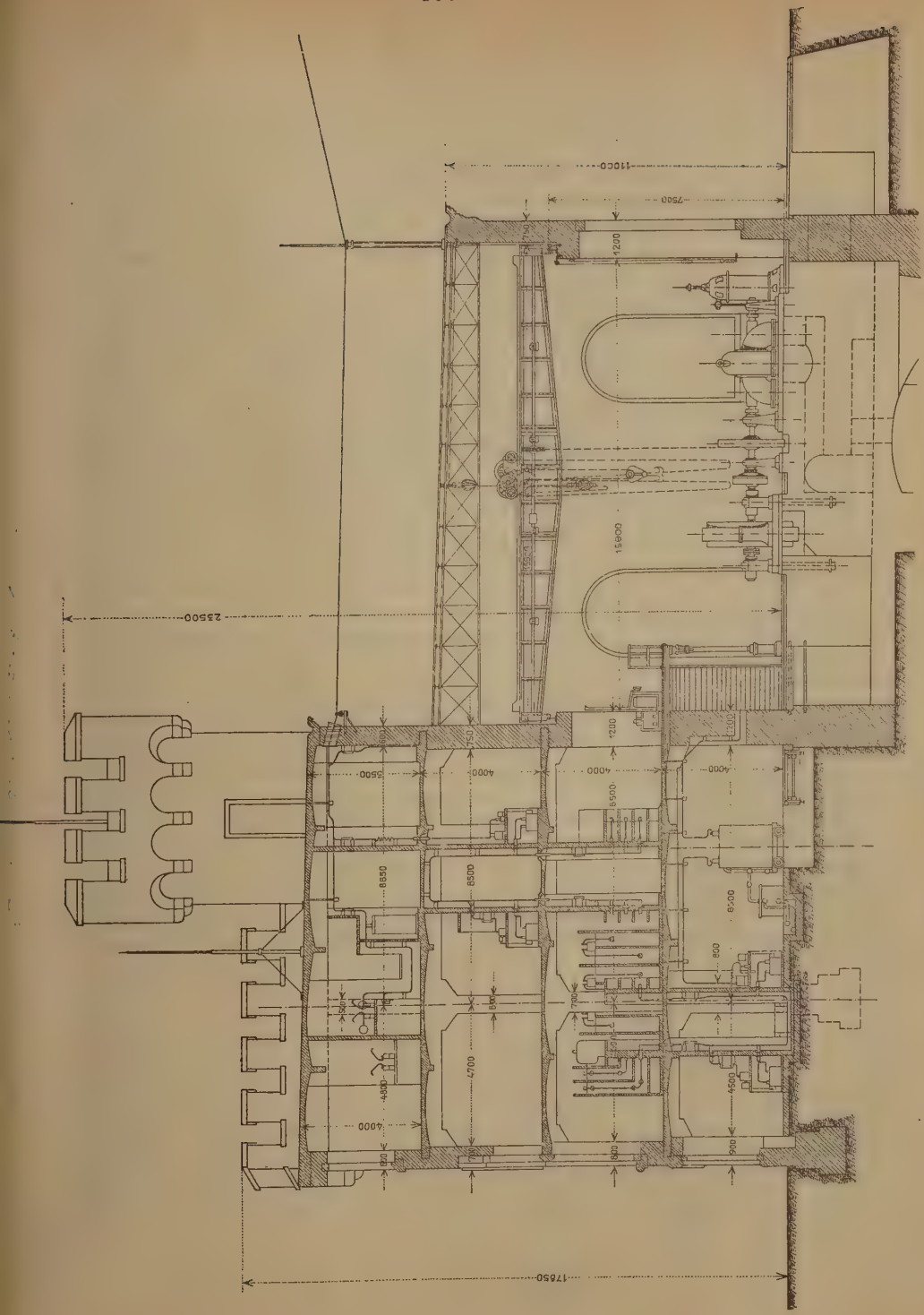


Fig. 27. — Section through Sarca power station. Trient-Malè Railway.

Nyiregyháza-Dombrád.

The rolling stock of this local line, which is 52 kilometres (32·3 miles) long and has a gauge of 76 centimetres (2 ft. 6 in.) includes the following:

Five petrol-electric motor coaches for passenger traffic; each coach weighs 11 tons and the capacity of its electric equipment is 20 kilowatts. The coaches are capable of hauling two or three 5-ton (4·9 English ton) trailers. (The yearly mileage is about 34,000 kilometres per motor coach.)

Two petrol-electric motor coaches for goods traffic (to be used occasionally also for passenger service) of 45 kilowatts capacity each.

One 50 horse power steam locomotive for goods traffic.

The work done by these vehicles in 1908 amounted roughly to 205,000 passenger train-kilometres and 45,000 goods train-kilometres (127,324 passenger train-miles and 27,962 goods train-miles); the average number of train journeys per diem was 13·4.

The cost of haulage (in hellers per train-kilometres) during eight months in 1908 was as follows:

—	For passenger motor coaches.	For goods motor coaches.	For the steam locomotive.
Fuel	8·5 to 9·75	20 to 24	17·3
Lubricating material	1·5 to 3	3·25 to 6	3
Other material	0·5 to 0·75	0·5 to 1	1
Train staff	5 to 6	9 to 16	13
Total haulage costs	15·25 to 19·25	32·75 to 47	43
Maintenance costs	2·5 to 6	8 to 31	10
Total costs	18·75 to 25·25	40 to 78	53

The above figures are based on a cost of petrol of 22 hellers per kilogram (1*d.* per lb.), Prussian coal at 36 kronen per ton (£1.10*s.* 5.19*d* per English ton) and wages at the rate of 40 hellers (4*d.*) per hour.

The maximum speed is 40 kilometres (24·8 miles) per hour, but on the Nyiregyháza-Sóstó section, 8 kilometres (4·97 miles) long, the speed is only 15 kilometres (9 3 miles) per hour because the track here follows the road. The consumption of petrol on this particular section is so high (on account of its being practically the same at high and slow speeds) that it is proposed to erect an overhead line on this section. The petrol engines would then be shut down during the passage through this section, but the electric motors would still be used for propelling the train. Perhaps, however, as mentioned in Appendix III, the difficulty will be solved by discarding the petrol-electric cars altogether.

APPENDIX II.

Description of the electric full-gauge railways under construction.

Vácz-Budapest-Gödöllő.

Characteristic features. — This is a standard-gauge main line, 50 kilometres (31 miles) in length, and was designed for electric traction from the very start. It will be the first railway in Austria-Hungary to be worked by single-phase current at 10,000 volts and 15 cycles per second. There are no sub-stations. Double catenary suspension for the overhead wire. Locomotives capable of developing 480 horse-power on the one hours' rating; motor coaches capable of 300 horse power on the same rating.

General notes on the railway. — The railway is single track about 50 kilometres (31 miles) in length (with approximately 10 1/2 kilometres [6·5 miles] of sidings) and serves the purpose of connecting the Rákospalota-Ujpest, Vácz and Gödöllő main line stations of the Hungarian State Railways. These places are already connected by steam railway lines; Rákospalota-Ujpest is 8 kilometres (4·95 miles), and Vácz 33 kilometres (20·5 miles), from the Budapest terminus (Westbahnhof) of the Budapest-Marchegg (Vienna) main line, while Gödöllő is 37 kilometres (23 miles) from the Budapest terminus (Ostbahnhof) of the Budapest-Miskolcz (Lemberg) main line.

The maximum gradient of the new line will be 1·5 per cent (for a length of 12·9 kilometres [8·0 miles]), while the sharpest curves will have a radius of 300 metres (15 chains). The number of curves will not be large. The difference in altitude between Vácz and Rákospalota is 5·29 metres (17 ft. 4 in.) and that between Gödöllő and Rákospalota 98·49 metres (323 ft. 1 5/8 in.). The maximum permissible speed is 50 kilometres (31 miles) per hour; the maximum weight per axle is 12 tons (11·8 English tons) the rails, of a maximum length of 12 metres (39 ft. 4 1/2 in) weigh 23.6 kilograms per metre (47·5 lb. per yard).

Reasons for adopting electric traction. — Electric traction was decided on, chiefly on account of the possibility of obtaining current from a steam-operated power station which will be erected at Rákospalota-Ujpest at one end of the line, and of the possibility of maintaining a frequent service with small train units. The power station referred to, will also supply current for lighting the state railway stations in and around Budapest.

The railway will serve for passenger and ordidary goods traffic, as well as for the transport of goods in bulk. At the beginning, it is intended to run 5,000 goods wagons per annum between Vácz and Gödöllő, without touching Budapest.

Single-phase current was proposed at the very inception of the line as the best solution of the problem, and no comparative calculations as to the costs with other kinds of current were made.

Power station. — The power station is situated at Rákospalota, 1 1/2 kilometre (0·93 mile) from the terminus nearest to Budapest. As already mentioned, it will also supply current for lighting the stations of the Hungarian State Railways in and around Budapest, and will not be worked by the railway authority.

The boiler equipment of the power station comprises five boilers with a heating surface of 350 square metres (3,767 square feet) each fitted with water tubes and chain grates, and built for a pressure of 12 atmospheres.

The feed water is heated by the exhaust steam from the pumps and the steam is superheated; no economisers are installed.

Each of the three generating sets consists of a horizontal 1,500 horse power compound engine which drives a 1,300 kilovolts-amperes alternator at 105 revolutions per minute. The low frequency of 15 cycles per second occasioned no difficulty in the design of the alternators.

A reserve unit (steam engine and generator) is also provided, and will be used both for traction and lighting purposes. Accumulators for equalising the load are not contemplated. The switch gear is now being designed.

Feeders. — The overhead line is fed direct with single-phase current at 10,000 volts and 15 cycles per second, sub-stations being therefore unnecessary.

A feeder of 35 square millimetre (0.0542 square inch) cross-section will be run from Rákospalota-Ujpest to Veresegyház (18·5 kilometres [11·5 miles] from the terminus) mainly with the object of maintaining the through traffic between Vácz and Gödöllő in case the overhead wire on the Rákospalota-Veresegyház section should happen to break. The feeder is a bare wire carried on the iron poles which support the overhead wire. The bell-shaped insulators are carried on iron cross pieces, being fixed to their pins by means of hemp and red lead. The overhead lines are protected against excess voltages by lightning arresters of the horn type. When short-circuits occur, the feeders are automatically switched off by circuit-breakers.

Overhead line. — The overhead wire will consist of grooved hard-drawn copper wire of 70 square millimetres (0·1085 square inch) cross-section and 97 per cent conductivity; it will have a tensile strength of at least 38 kilogrammes per square millimetre (54,046 lb. per square inch) and will be suspended throughout at a height of 5 ½ metres (18 ft. ½ in.) above the rails.

The construction of the overhead equipment will be the same as that adopted for the Blankenese-Ohlsdorf and Rotterdam-Hague-Scheveningen railways. The overhead wire will be suspended from a double catenary and will be kept at a uniform tension by automatic trolley wire tighteners of the Siemens-Schuckert-Werke type. The overhead wire will be arranged in zig-zag fashion, and will be supported by an auxiliary wire of 6 ½ millimetres diameter, the latter in turn being supported by a cable with nineteen strands and of 50 square millimetres (0·0770 square inch) cross section. The insulation to earth is double throughout, and will be obtained by porcelain insulators.

The poles will be iron lattice poles of rectangular or square section and will be spaced at intervals of 100 metres (328 feet) on straight stretches. A pole for anchoring purposes will be erected in the middle of curves. The rectangular poles will consist of two girders of U-form (Nos. 8, 10 or 12) connected together by spirally-arranged flat iron strips. The square poles will be composed of four angle irons, suitably braced together. The maximum tensile stresses are not to exceed 1,200 kilogrammes per square centimetre (17,067 lb. per square inch).

The overhead wire in the sidings will be arranged in the same manner as on the main line.

The current will return through the rails, for which purpose the latter will be suitably bonded.

Rolling stock. — Four goods locomotives (of which one will be kept in reserve), eleven motor coaches (two of which will be kept in reserve) and six passenger trailers are now being built.

Each locomotive has two two-axle bogies and will be driven by two motors. The motor frames are rigidly fixed to the bogie trucks. The motors drive through gearing on to a counter-shaft, from which the power is transmitted to the two axles of each bogie by means of cranks and connecting rods. The high centre of gravity will ensure sweet running. The maximum speed on straight level stretches will be 40 kilometres (24·8 miles) per hour.

The motor coaches will also be provided with

two two-axle bogies and two motors, but only two of the four axles will be driven. One motor will be spring-suspended inside each bogie, and will be supported from the driving axle, to which the power will be transmitted by toothed gearing. The maximum normal speed of the motor coaches will be 50 kilometres (31 miles) per hour.

The bogies of all the vehicles can be run from under the carriages, thus ensuring accessibility to the motors.

Each locomotive motor develops 240 horse-power on the one hours' rating when running at 700 revolutions per minute; the corresponding figures for the motors of the motor coaches are 150 horse-power at approximately 850 revolutions per minute. The motors are provided with a ventilating fan built into the armature, but they are not artificially cooled.

The motors are of the single-phase series type with compensation winding and electrically-displaced auxiliary field are not provided with commutator resistances. The armature slots are half closed, while the stator slots are open, being closed, after the winding has been inserted, by wooden keys. The stator winding consists of flat copper bars on edge, which are connected up according to the Richter method. The armature winding is also composed of flat coppers bars on edge; it is a loop winding with equalising connections. The armatures of the locomotive motors have a diameter of 670 millimetres (2 ft. 2 3/8 in.) and an effective core length of 310 millimetres (1 ft. 5/16 in.); the armatures of the motors coaches are 540 millimetres (1 ft. 9 5/16 in.) in diameter and have an effective core length of 270 millimetres (10 5/8 inches). The air gap is 2 1/2 millimetres (3/32 inch) in all motors.

The weight of the locomotive motor is about 4 tons (3·9 English tons), or complete with counter shaft, gearing and gear case 6 tons (5·9 English tons) in round figures; the coach motors weigh about 3 tons (2 95 English tons) each, including gearing and gear case. Current is collected in all cases by two bow collectors which reverse their provision automatically when the direction of travel is changed. These collectors are worked by compressed air, but they can also be worked by a hand-operated mechanical arrangement if necessary. The two current collectors are always used simultaneously.

The high-tension wires are carried on porcelain insulators, while the low-tension current is conveyed through cables.

The car transformers are oil cooled. The transformers on the locomotives weigh approximately 5 1/2 tons (5·4 English tons), those on the motor coaches about 4 tons (3·9 English tons).

Speed regulation is obtained by reducing the voltage of the main transformer by means of magnetically operated switches. The function of the main controller switch in the driver's compartment is limited to switching on the current to the transformer regulating switch referred to. Multiple-unit control is not contemplated. All working parts are interchangeable.

In ordinary service, the braking is performed by compressed-air brakes of the Westinghouse type; hand brakes are also provided as an auxiliary.

Signals are given by whistles worked with compressed air.

The carriages are lighted by incandescent lamps connected in series, and are heated by electric radiators of the Prometheus type.

The gradients are not sufficiently steep to make regenerative control profitable.

The total weight of a locomotive is about 44 tons (43·3 English tons) (of which about half is due to the electric equipment), and that of a motor coach about 39 tons (38·4 English tons) (of which about 16 tons [15·7 English tons] is represented by the electrical portion).

The motor coaches have seating accommodation for twenty second class and thirty third-class passengers.

The mechanical portion of the locomotives is being supplied by F. Ringhoffer in Smichov, near Prague, and that of the motor coaches by the Ungarischen Waggon- und Machinenfabriks

Company in Győr (Raab); the whole of the electric equipment for the power station and railway has been or will be supplied by the Hungarian Siemens-Schuckert Werke, who also supplied the complete designs of the rolling stock.

St. Pölten-Mariazell-Gusswerk (Niederösterreichisch-steierische Alpenbahn or Pielachtal Railway) (1).

Characteristic features. — This is a local line 91 kilometres (66·5 miles) long, with a gauge of 76 centimetres (2 ft. 6 in.). The traffic is comparatively very heavy. Current is supplied from two water power stations working in parallel with one another and with a power station, equipped with Diesel engines, which is started up when necessary. The railway is worked with single-phase current at 6,000 volts and 25 cycles per second. The locomotives have six axles and are capable of developing 550 horse power on the one hours' rating.

General notes. — The local railway, St. Pölten-Mariazell-Gusswerk, is 91·335 kilometres (56·754 miles) long, and is single track with a gauge of 76 centimetres (2 ft. 6 in.).

It is the property of the province of Lower Austria and is worked at present by steam locomotives. The very heavy passenger traffic is occasioned by excursionists to the picturesque Mariazell district and by the temporarily very heavy influx of pilgrims on their way to Mariazell. The chief condition for the success of electric traction is therefore fulfilled.

The maximum gradient is 2·5 per cent on an incline 16 kilometres (10 miles) long. There are many curves, no less than 56 per cent of the line situated in the mountains lying in curves. The sharpest curve has a radius of 90 metres (4 1/2 chains). The difference in altitude between the termini is 460·7 metres (1,411 feet) while the difference in altitude between the highest and lowest points of the lines is 622·4 metres (2,042 feet). Maximum weight per axle 7 1/2 tons (7·38 English tons). The maximum speed with steam traction is 30 kilometres (18·6 miles) per hour and with electric traction from 45 to 50 kilometres (28 to 31 miles) per hour (see figures 28 and 30). The rails weigh 21·8 kilograms (43·9 lb. per yard) per metre and are in length 9 metres (29 ft. 6 in.).

Reasons for adopting electric traction. — The chief reason for adopting electric traction was the traffic, which was heavy from the very opening of the line and could hardly be increased any further with steam traction. The alternative solution, viz. to lay down a second track, was commercially out of the question on account of the difficulties of the terrain, necessitating many new bridges, tunnels, etc. At the same time, electric traction not only made it possible to increase the speed of travel, but also promised good commercial results.

It was not thought necessary to construct an experimental line, but similar railways abroad were carefully studied. In order to aquaint the staff gradually with the new system, the locomotives will not be placed in service all at once, but in batches.

Choice of current; technical and commercial comparisons. — The current adopted is single-phase at 25 cycles per second, the feeder voltage being 25,000 volts and the line pressure 6,000 volts.

Reasons for adopting single-phase current. —

(1) *Elektrotechnik und Maschinenbau*, Vienna, 1908 und 1909; *Elektrotechnik und Maschinenbau*, Potsdam, 1908, N° 21; *Elektrotechnische Zeitschrift*; Berlin, 1908, N° 33; *Elektrotechnischer Anzeiger*, Vienna, 1908, N^{os} 29 and 30; *Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines*, Vienna, 1908, N° 15; *Rundschau für Technik und Wirtschaft*, Prague, 1909, N° 8; *Bericht des Landesausschusses von Niederösterreich wegen Errichtung eines Landeselektrizitätswerkes*, 1907; *Bericht des Eisenbahnausschusses des Landes Niederösterreich betreffend Beschaffung elektrischer Traktionsmittel*, 1907.

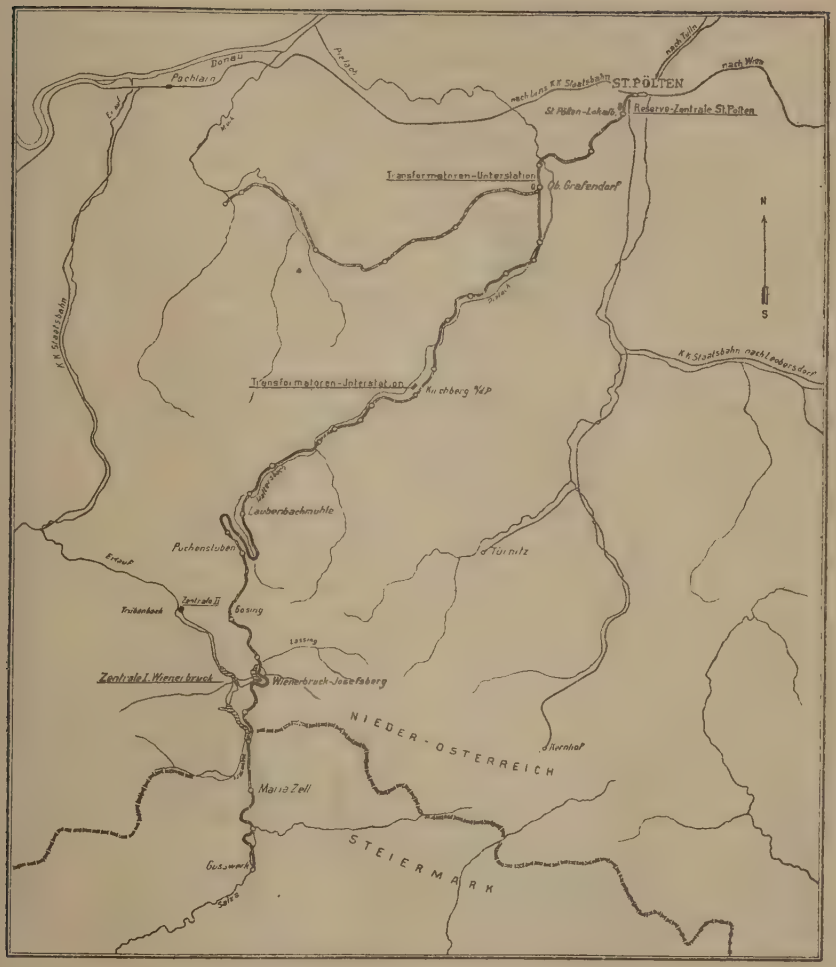
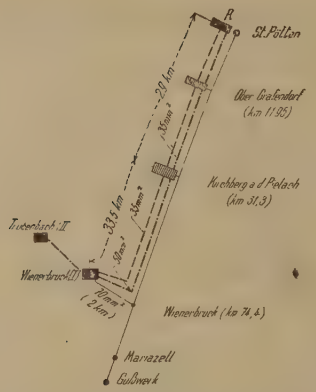


Fig. 28. — Plan of St. Pölten-Mariazell-Gusswerk line.

Explanation of German terms: Nieder-Oesterreich = Lower Austria. — Zentrale = Power station. — K. K. Staatsbahn nach = State Railways to. — Donau = Danube. — Transformatoren-Unterstation = Transformer substation. — Nach Wien = To Vienna.

Single-phase current was selected for commercial reasons, after preliminary calculations had shown that this kind of current was decidedly the best for railway purposes, although the three phase system would have been more advantageous as regards the simultaneous supply of current for power and lighting to private consumers. However, the commercial superiority of the



= Trolley wire connected with power station I, 6,000 volts.
= Traction feeders, 25,000 volts single phase.
= Feeders for private consumers, 25,000 volts, three phase.
I. II. . . . . = Water power stations.
R . . . . . = Reserve power station with Diesel engines.

Fig. 29. — Diagrammatic plan of St. Pölten-Gusswerk line.

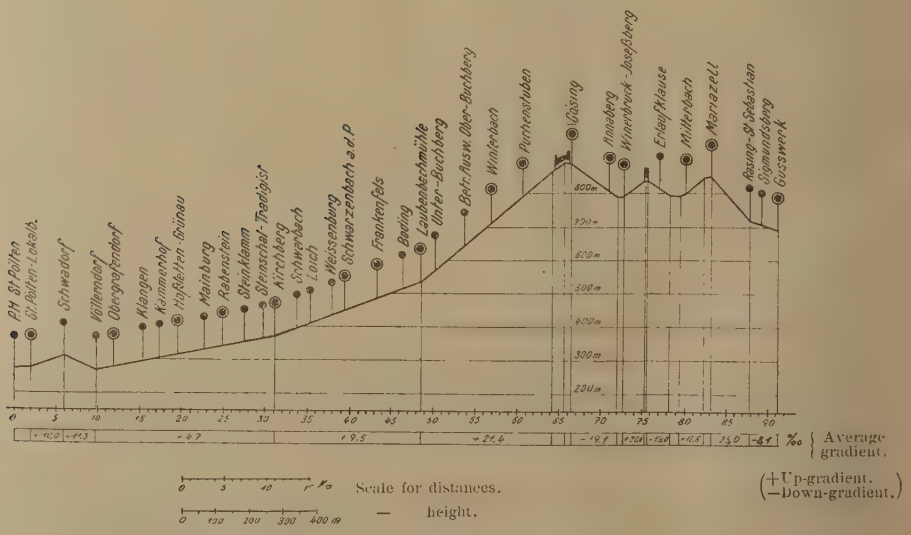


Fig. 30. — Profile of St. Pölten-Gusswerk line.

single-phase system was so marked that it was necessary to work out a detailed schedule of costs for both cases.

The capital expenditure is considerably less for the single-phase system than for the continuous-current system. The power station would have cost the same in both cases, for no saving could have been effected by adopting a mixed system (three phase for the transmission and continuous current for the railway) because any saving that might have been effected by reducing the amount of copper required for the transmismission lines would have been neutralised by the extra expenditure involved in having to erect a third wire and employ poles $^1/_2$ metre longer than in the other case.

The sub stations which would have had to be built for a continuous-current line pressure of 1,500 volts — the highest continuous-current voltage which was practicable at the time electric traction was planned — would have cost at least 1,500,000 kronen (£62,400) as compared with 120,000 kronen (£4,992) for the single-phase system. The line wires for the single-phase system will cost 1,900,000 kronen (£79,440) and of this 300,000 kronen (£12,480) at the highest could have been saved by adopting a lower voltage; the expenditure on copper, poles and station equipment and the cost of erection would have been the same in both cases. The continuous-current locomotives would have cost about 250,000 kronen (£10,400) less than those of the single-phase type, but the difficulties of building motors of large capacity to suit the narrow gauge would not have been less. The adoption of the continuous-current system would therefore have increased the total capital expenditure by 750,000 kronen (£31,200).

If the three phase system had been adopted throughout, the highest overhead line pressure would have been 5,000 volts; an additionnal feeder would have been necessary between Wienerbruck and Mariazell and the sub-stations would have cost more. The expenditure on the overhead lines in the stations, with their numerous sidings, would have cost considerably more. The cost of the locomotives, too, could not have been reduced in spite of the direct supply of energy, because the necessary speed regulation (50 kilometres [31 miles], per hour on the level and 30 kilometres [18·6 miles] per hour on a 2·5 per cent gradient) could only have been obtained by increasing the weight of the motors (in the case of the cascade system being employed) or by providing costly switch-gear (in the case of the speed regulation being obtained by changing the number of poles).

The single-phase system is also preferable from the « running costs » point of view. In the case of continuous current, the advantages which might have accrued from the lightness, high efficiency and low maintenance costs of the motors would have been more than counterbalanced by the increased interest on and depreciation of the capital expenditure and the higher costs for running the converter sub-stations. In addition, the single-phase motor fufilled even at the time all service requirements, and it could be confidently predicted that improvements would occur as time went on.

Single-phase motors are considered as being at least equal to three phase motors from the commercial point of view, and as, moreover, the three-phase system would have involved larger capital expenditure and higher maintenance costs for the line wires, there was little inducement to adopt this system; in addition, the double overhead wires required for this system would have impaired the reliability of the service.

Reasons for selecting the voltages determined on.— At the time when the plans were prepared, the maximum pressures which were considered practicable were 50,000 volts for the feeder lines and 10,000 volts for the overhead wires, but only such pressures were adopted as appeared to be necessary for economical working. In the special conditions prevailing at that time, the pressures decided on were 25,000 and 6,000 volts respectively. The overhead equipment, however, is being so constructed that the voltage can be increased later on to 10,000 volts if neces-

sary. An increase of the transmission pressure beyond 25,000 volts (on account of the extra cost for insulators which would have been involved thereby) did not promise any commercial advantages.

Reasons for adopting a frequency of 25 cycles per second. — The choice lay between 15 and 25 cycles per second, the latter being considered the upper limit for a satisfactory working of the motors. The unavoidable increase in the cost of the power plant for a frequency of 15 cycles per second, would have counterbalanced the saving in the transmission wires, and it was important in this particular case, to keep the capital expenditure as low as possible by adopting the same frequency for traction, power and lighting. The experts, who prepared the plans and specifications, thought, however, that it might be preferable, for both technical and commercial reasons, to adopt different frequencies for traction and power and light on larger networks, and that int he present case, uniformity in the frequency was one of the deciding factors. At that time, a frequency of 25 cycles per second seemed to be the generally-accepted standard, while the frequency of 15 cycles per second, which is largely employed in Switzerland, Baden and Sweden, is of more recent date.

The decision was also influenced by the fact that the existing power station at St. Pölten was designed for a frequency of 25 cycles per second.

Water power stations. — The normal supply of current will be obtained from two water-power stations at Wienerbruck and Trübenbach (managed by the province of lower Austria), assisted by a reserve power station, equipped with Diesel engines, at St Pölten (for clearness' sake, the map, fig. 28, is not drawn to scale). The water power installations were all the cheaper because they required a comparatively small capital expenditure; in particular the old reservoirs could be very greatly extended at small cost.

Power station No. I at Wienerbruck (already completed) is supplied with water from the upper reaches of the river Erlauf across which the « Wienerbruck » dam has been built (the water storage is 300,000 cubic metres [1,059,498 cubic feet] corresponding to 100,000 kilowatts-hours) and from the lower part of the Lassing, a tributary to the Erlauf, across which another dam, known as the « Erlaufklause » has been erected, the water storage being 2,000,000 cubic metres (706,332 cubic feet) corresponding to 600,000 kilowatts-hours. The heads are 157 and 171 metres (515 and 561 feet) respectively. Figure 31 represents the hydraulic conditions, including the quantities of water flowing in the two rivers, during three years.

Power station II at Trübenbach, the tunnelling for which was commenced at the end of 1909, will be driven by the water from power station I (Erlauf), which is collected by a third dam, the « Oetschergraben » dam. The storage capacity is 700,000 cubic metres (2,472,162 cubic feet) corresponding to 400,000 kilowatts-hours. The average quantity of water available over the whole year is 2 cubic metres (70·6 cubic feet) per second, the effective head being 130 metres (426 ft. 6 in.).

A third water-power has been secured at Urmannsau, and is intended for running a power station No III. The average quantity of water, taken over the whole year is here 2 8 cubic metres (98·8 cubic feet) per second, the effective head being 93 metres (305 feet).

Precision governors of the Voilt type with auxiliary motors and oil pumps will be used. The irregularities in speed are guaranteed not to exceed 1 $^1/_2$. 3 and 6 per cent with fluctuations in the load of 25·50 and 100 per cent respectively. Two-thirds of the alternator output is single phase. There is also in each power station a turbine with exciter, capable of supplying exciting current to three alternators. All the exciters of a power station are connected to a common set of continuous-current bus bars. The admissible voltage fluctuation for traction is 15 per cent of normal. The voltage is regulated by regulators of the Dick type. Power sta-

tion III will be built on the same lines as described above, and is to have a turbine capacity of 3,500 horse power; the ultimate capacity has not yet been decided upon.

—	Power station I.	Power station II.
Horse power of turbines (12 hours full load and 12 hours 1/2 load)	3,500 horse-power.	3,700 horse-power.
Ultimate capacity	5,000 to 6,000 horsepower (approximately 4,500 kilowatts).	4,000 horse power (approximately 3,000 kilowatts).
Number of sets consisting of 1,000 horse power Pelton wheels and 1,350 kilovolts-amperes three-phase alternators	4	4
Number of sets consisting of 2,000 horse power Pelton wheels and 2,700 kilovolts-amperes three-phase alternators	1	...
Revolutions per minute	375	750
Total capital expenditure (per kilowatt):	Kronen. £	Kronen. £
Structural part	2,900,000 (642)	2,090,000 (696)
Turbines and pipe lines	150,000 (33)	120,000 (40)
Electrical portion	900,000 (200)	690,000 (230)
Total	3,950,000 (875)	2,900,000 (966)

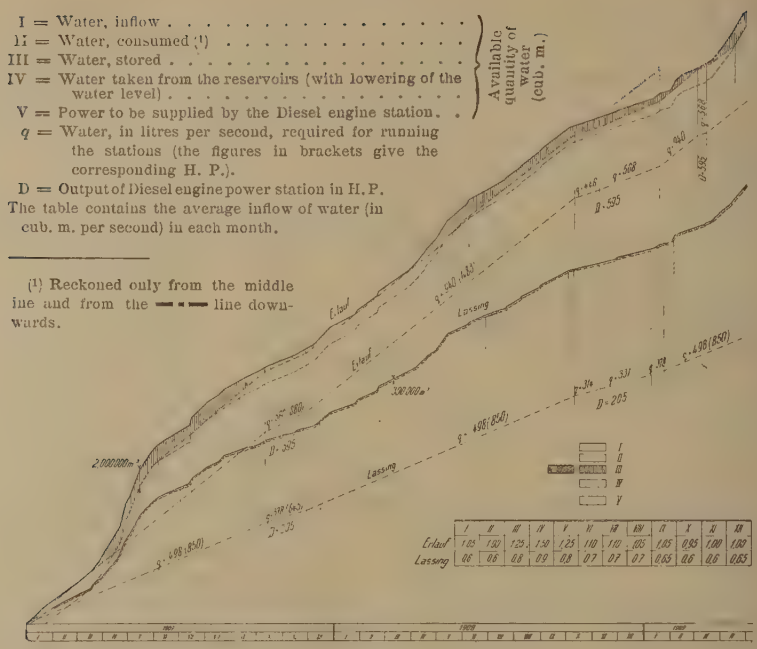
Reserve power station with Diesel engines at St. Pölten. — The chief object of this power station is to supply energy in case the water power stations fail, but it will be used to meet exceptionally heavy demands (occasioned by heavy pilgrims traffic on two consecutive festal days) and to equalise the loads on the other stations during fluctuations in the water supply. It is assumed that the Diesel power station will have to be run on full load during approximately three months of the year; as far as possible, however, water power will be drawn upon, and when this is no longer sufficient, the Diesel engines will be set in motion and run at full load (the working together of the power stations is represented in fig. 31).

It is intended to meet the peak loads for the present by water-power alone and it must be left to future experience to decide whether load equalising arrangements or equalising of the traction and private power lighting supplies is desirable.

The Diesel engines will be run with crude oil (from which petrol and paraffin have been extracted, of a calorific value of 10,500 calories (41,667 British thermal units). This fuel is cheap and can be easily stored without danger. There were several reasons for placing the station at St. Pölten. For one thing, the oil can be brought to the power station and on the full-gauge railway and directly filled into the tanks without the necessity of transferring the oil on to the narrow-gauge line, and another advantage is that the power station can be used for supplying, without appreciable loss, the large amount of current required for private consumers in St. Pölten.

There will be two 800 horse power Diesel engines, running at 152 revolution per minute, and the station can be extended later on to accommodate a third set. The guarantees given by the engine contractors as regards perfect running in parallel with the municipal power stations are important. The experiments as regards running in parallel with the municipal power station of St. Pölten, which contains a turbine, a steam engine and a gas engine, have given so far quite satisfactory results.

The alternators, which will be direct coupled to the engines, will have a capacity of 700 kilovolts-ampère three-phase or 420 kilovolts-ampère single-phase. The low frequency employed


I = Water, inflow
II = Water, consumed (1)
III = Water, stored
IV = Water taken from the reservoirs (with lowering of the water level)
V = Power to be supplied by the Diesel engine station.
q = Water, in litres per second, required for running the stations (the figures in brackets give the corresponding H. P.).
D = Output of Diesel engine power station in H. P.
The table contains the average inflow of water (in cub. m. per second) in each month.
Available quantity of water (cub. m.)
(1) Reckoned only from the middle line and from the — · — line downwards.
Erlauf
Lassing
2.000.000 m³
300.000 m³
D = 205
D = 595
I
II
III
IV
V

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Erlauf	1.05	1.30	1.25	1.50	1.25	1.10	1.10	1.05	1.05	0.95	1.00	1.00
Lassing	0.6	0.6	0.8	0.9	0.8	0.7	0.7	0.7	0.65	0.6	0.6	0.65

Fig. 31. — Curves representing the water conditions during 2 ½ years. St. Pölten-Gusswerk line.

occasioned no difficulties in design, but it caused an increase in price compared with the cost of an installation for 50 cycles per second.

The capital expenditure (in kronen) for the present installation (1,600 horse power or 1,200 kilowatts in round figures) is as follows :

Buildings	165,000 or 140	kronen per kilowatts.
Mechanical part	420,000 or 350	— —
Electrical equipment	240,000 or 200	— —
Total, including sundry expenses	850,000 or 708	kronen per kilowatts.

Switchgear and power station. — The switchgear had to fulfil the following conditions :

1° Uniformity in design for all the power stations;

2° Greatest simplicity and reliability;

3° Complete separation of high-tension and low-tension circuits;

4° Separation of traction and private supply circuits, but with the possibility of switching any of the generators on to the one circuit or the other;

5° Arrangement of the switchgear on various floors as follows :

Water-jet earthing devices and line fuses in the cellar,

Switch apparatus and measuring instruments in the basement,

Lightning arresters and wall bushings for the out-going line wires on the floor above.

Feeders. — The traction network will be supplied with single-phase current and the lighting

and power network with three phase current, the pressure and frequency being in both cases 25,000 volts and 25 cycles per second respectively. The feeders are separate, but are carried on the same poles. If necessary, the traction network can be connected with the lighting network by means of change-over switches in the power station and sub-stations (see fig. 29).

The two traction sub-stations are situated at Kirchberg on the Pielach and Ober-Grafendorf respectively. They are supplied on an average with energy amounting to about 1,000 kilowatts. Each is equipped with a transformer of 900 kilovolts-ampere continuous rating, with a very large overload capacity. At the St. Pölten power station, there is a portable boosting transformer. The drop in voltage will not exceed 15 per cent at the most under ordinary service conditions, but may amount to anything up to 30 per cent on the Wienerbruck-Mariazell section when the pilgrim traffic is heavy. There is no feeder to this portion of the line at present, but the poles could be made use of for carrying a feeder, if required, and the erection of a third substation has also been considered.

The feeders, which are overhead throughout, are carried on iron poles from 10 to 12 $^1/_2$ metres (32 ft. 10 in. to 41 feet) long (strong lattice poles are used at corners) of 22*a* or 24*a* standard Austrian section. The poles are spaced at distances varying from 40 to 50 metres (131 ft. 3 in. to 164 feet) the average being 42 metres (137 ft. 10 in.). The insulators are cemented to their pins, and the latter are screwed separately into the poles. The feeders are carried round the tunnels.

Protection against excess voltages is secured by water-jet earthing devices, lightning arresters of the "horn" type with choking coils and oil resistances and automatic maximum circuit-breakers with time limit device, which are installed in all the power stations and the Kirchberg sub-station.

The capital expenditure for the feeders (including a corresponding share of the pole line) amounted to 17·5 kronen per metre (13*s.* 3·76*d.* per yard); the capital cost of a sub-station, without spare transformer, was 50,000 kronen (£2,080) or 55 kronen (£2·5*s.* 9*d.*) per kilowatt.

Overhead wires. — The overhead line is of grooved copper wire of 80 square millimetres (0·124 square inch) cross-section, and is suspended by a double catenary of the Siemens-Schuckert Werke Type. The catenary cable is fixed to the auxiliary wire at points 6 metres (19 ft. 8 in.) apart, while the overhead wire is supported from the auxiliary wire every 3 metres (9 ft. 10 in.). The overhead wire is suspended in zig-zag fashion over the centre of the track. The conductivity coefficient of the copper is 57; its tensile strength is 37 kilograms per square millimetre (54,046 lb. per square inch). The standard height of the wire above the rails is 5 $^1/_2$ metres (18 ft. $^1/_2$ in.) and the smallest height in tunnels is 3·7 metres (12 ft. 1 $^{11}/_{16}$ in.). The overhead wire is doubly insulated from earth. Automatic trolley wire tighteners, actuated by weights, are interposed in the overhead line at intervals of 1 $^1/_2$ kilometres (0·93 mile).

The iron brackets for the overhead wire are carried by the same poles that support the feeders. The poles and brackets are designed for a safety factor of 4 (11 kilograms per square millimetre [15,645 lb. per square inch]) with a wind pressure of 125 kilograms per square metre (25·8 lb. per square foot) and a temperature of —20° C. (—4° Fahr.). The minimum distance between poles in curves is 25 metres (27·34 yards).

The wires in the stations, which aggregate 22 kilometres (13·6 miles), are suspended from iron structures of bridge form.

The rails are bonded in a manner similar to that adopted on the Vienna-Baden line, and cross bonds are provided every 100 metres (109 yards). The calculations were based on an impedance of 0 7 ohms, but measurements have shown that the impedance of the overhead wire and the rails is only 0·5 ohms.

*

The capital expenditure for the overhead line and return through the rails was as follows : On single track open line, 16 kronen per metre (12*s*. 2·07*d*. per yard) of railways; in stations, 25 kronen per metre (19*s*. 0·23*d*. per yard) of track.

These sums include 3 5 and 14 kronen (2*s*. 7·95*d*. and 10*s*. 7·81*d*. per yard) respectively for the poles, brackets and other supporting devices for the overhead wire.

Electric locomotives. — At present seventeen locomotives of the same size and type are to be used for hauling trains of all classes. Express trains and heavy goods trains are to be drawn on hilly stretches by two locomotives where necessary. About four steam locomotives are to be kept in reserve for the present for emergencies.

The mechanical portions of sixteen locomotives were supplied by the Linzer Lokomotivfabrik formerly Kraus, while that of one locomotive are from the Grazer Waggon- und Maschinenfabriks A. G.; the electrical equipment of the whole installation was supplied by the Austrian Siemens-Schuckert Werke.

The locomotives are of the motor coach type (see fig. 32). They have two three-axle bogies, each of which is fitted with a motor. Altogether there are six driving axles, the weight on each being 7 1/2 tons (7·38 English tons). The weight of a locomotive, ready for service, is 45 tons (44·3 English tons), of which 21 tons (20·7 English tons) are represented by the mechanical parts, 12 tons (11·8 English tons) by the two motors with driving gear, 7 tons by the two transformers. 4 tons (3·93 English tons) by the switch gear and auxiliary apparatus and finally nearly 1 ton (0·98 English ton) by the two current collectors.

The maximum speed (which is limited by the permanent way) will be 50 kilometres (31 miles) per hour. The couplings etc. are designed for a pull of 7 tons (6·9 English tons).

Each locomotive is provided with two series commutator motors with commutation poles (without resistance connections in the armature) of the Siemens-Schuckert Werke type.

Since each motor can develop 250 horse-power on the one hours' rating, it will be seen that a locomotive can develop 500 horse-power for one hour — an exceptionally large capacity considering the narrow gauge. Each motor weighs 4 tons (3·93 English tons) (16 kilograms [35·2 lb.] per horse-power), or complete with gearing 6 tons (5·9 English tons). As shown in figure 33, the power is transmitted from the motors to the wheels by means of toothed gearing, crank and connecting rods. The whole driving gear is spring suspended, and this is a valuable property in view of the numerous curves and rail superelevations. The two cranks of each motor are at right angles to one another, so that the torque at the wheels is always constant. The centre of gravity is high, in accordance with well-known practical requirements, so as to ensure sweet running, easy running in curves and accessibility to the motors. The upper half of the motor frame can be lifted up (after undoing a few bolts) by means of the eye bolts which are cast on. The brush spindles are fixed on metal rings which are guided by rollers and which can be rotated through 180°, so that every part can be made accessible. During service these rings are fixed by screws and lifted off the rollers. The lower half of the motor frame is provided with projecting arms which surround the lower gear wheel bearing and are fixed to the bogie frame. A notable detail, which makes for safety against derailment in curves, is the placing of the turning pivot *outside* the motors; the centrifugal forces acting on the motors in curves have therefore the tendency to press the leading wheels of the bogies against the inside rails and this facilitates the adjustment of the bogies when entering from a curve into a straight section. The arrangement just described is not employed in the six-axle locomotives of the Seebach-Wettingen line.

Each of the ten-pole motors is fed at about 250 volts from its own transformer. A special fan is provided for cooling the commutator, armature and field by a forced blast. The

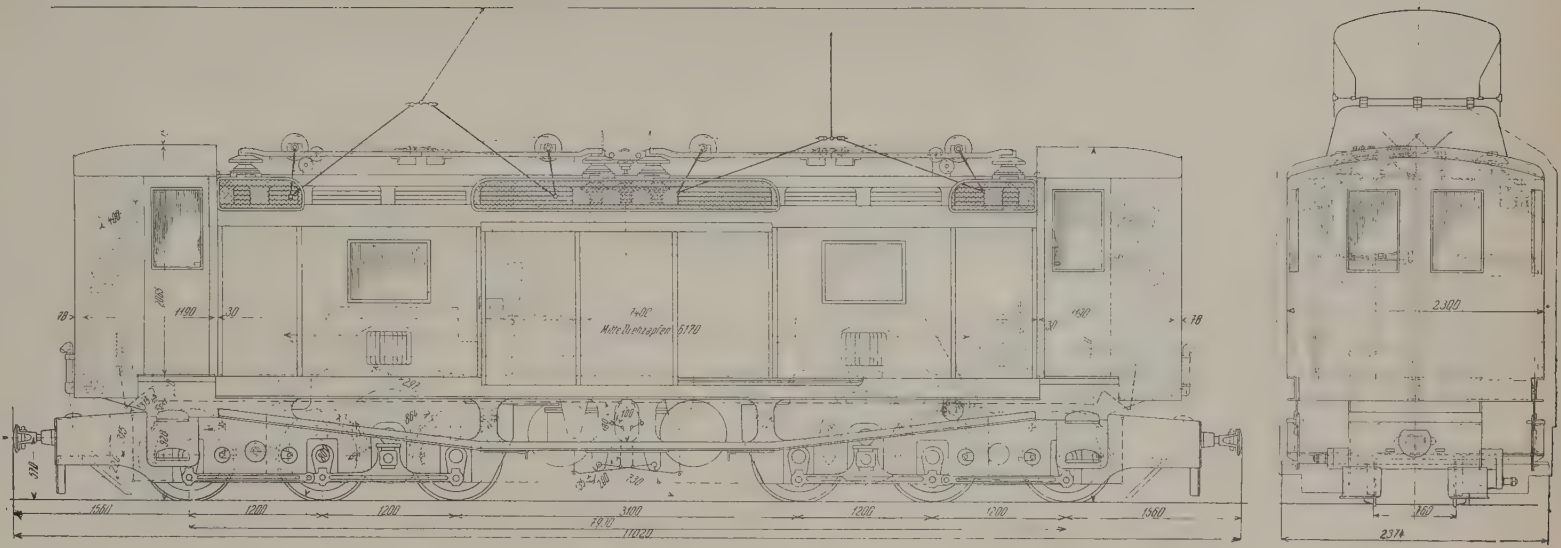


Fig. 32. — Electric locomotive (500 H. P., 45 tons [44·3 Engl. tons]). St. Pölten-Mariazell-Gusswerk line.

Explanation of German term : Mitte Drehzapfen = Central axis.

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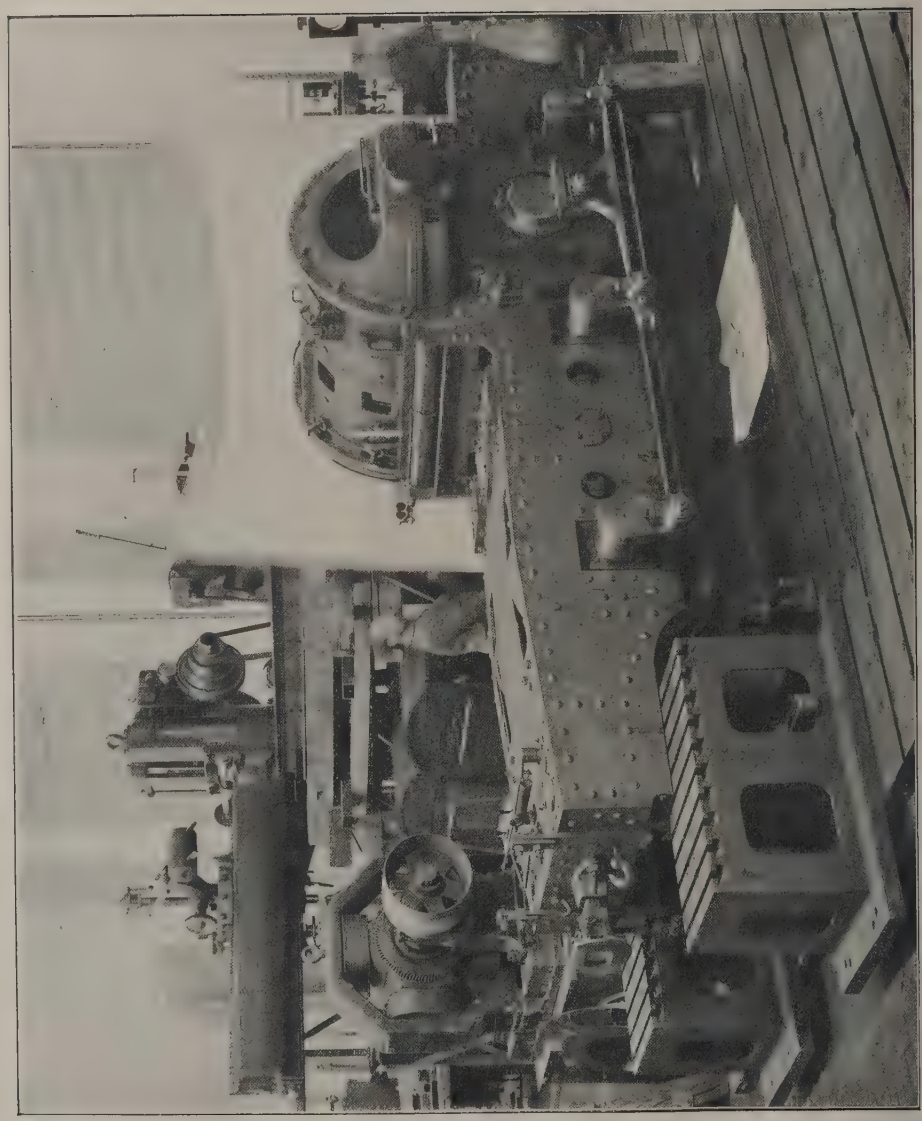


Fig. 33. — Bogie of locomotive with 250 H. P. motor (gauge 76 centimetres [2 feet 5 15/16 inches]). St. Pölten-Gusswerk line.

maximum speed is 1,000 revolutions per minute.

Speed regulation is obtained by altering the secondary transformer voltage in seven steps. This is done by step-by-step switches which are controlled by relays. The transformers are of the core type and are placed in the centre of the locomotive. Their combined capacity is 500 kilo-volt-amperes. After opening the side doors, they can be easily moved (on rollers) and quickly replaced. The transformers are placed in oil tanks with external cooling ribs (see fig. 34), and the oil tanks are connected with an oil reservoir at a higher level in such a way that the oil cannot be jerked out of the narrow space between the transformer and the tank even by violent shocks.

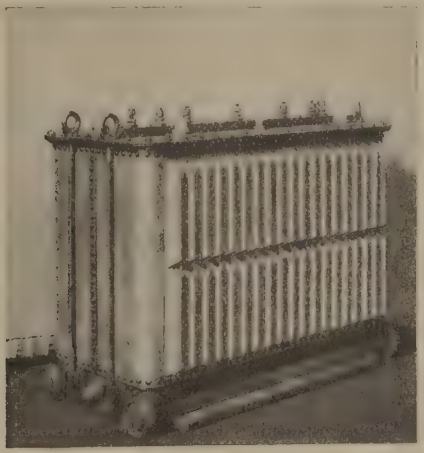


Fig. 34. — Locomotive transformer. St. Pölten-Gusswerk line.

The high-tension current is conveyed by two bow collectors (of the same type as those used on the Vienna-Baden line) from the overhead line and through well-insulated porcelain bushes into the high-tension compartment. Outside of this high tension compartment there are only low-tension conductors, partly in the form of cables and partly in the form of bare conductors carried on insulators. The bow collectors are worked by a hand winch which is highly insulated. The collectors are designed for very considerable variations in the height of the overhead wire over rail level (from 3·7 to 5·5 metres [12 ft. 1 in. to 18 feet]). The collector bows proper change their position automatically when the direction of travel is reversed. The necessary spring pressure for the collector bows is obtained from a flat torsion spring which is rigidly clamped at its centre.

Only one of the two bow collectors is used at a time. A safety screen is fixed at both sides of the roof as a protection against accidental contact with the bases of the bow collectors which are mounted rather low.

The service brakes are vacuum brakes of the Hardy type.

There are two motor-driven vacuum pumps, one for the locomotive and one for the coaches. They are operated from brake boxes of the type already described in connection with the Vienna-Baden & Trient-Malè lines. The brakes are only applied on four driving axles. A hand-operated brake is provided as reserve.

The equipment also includes a signal horn

which is worked by the exhaust from the vacuum pumps; it is of the same type as that employed on the motor coaches of the Trient-Malè line.

The two compartments for the driver are connected by a passage, the two motors being bridged over by steps.

At present, only one driver will be employed, who will take up his position in the rear compartment.

Provisions have been made for controlling two locomotives from one of the driver's compartments by means of multiple-unit control.

Regenerative control on down gradients (on which up to 7 per cent of the energy might be regained) will not be employed.

For one thing, the locomotives would have been more complicated and, further, it would not have been possible in this particular case to reduce the peak loads; on the contrary, the load fluctuations on the power stations would have been rendered still more unequal than they are at present.

Finally, it must be remembered that the motors would have been loaded for a longer time, and it seemed more advantageous to permit the motors to cool down on declines so as to be able to overload them more on up-gradients.

The train lighting will be carried out by incandescent lamps fed from the transformers. As regards electric heating, tests will first be made on two trains with radiators of the Electra and Brockendorf types. Should electric heating not prove a success (and this, in my opinion, is not probable considering the low cost of the current), the German system of heating with compressed fuel or else special boilers on the locomotives for supplying steam to the existing steam heating arrangements will be adopted.

The cost of a locomotive was 87,000 kronen (£3,622.10*s*.) in round figures.

Figure 36 is the simplified diagram of connections for the locomotive. The HT current is switched on by operating the lever HS by hand. When the multiple-unit control is employed, the switching in is performed by the solenoid *e*, fed through an auxiliary circuit from the leading locomotive. When the permissible overload is exceeded, HS is automatically opened by the solenoid *a*, either by means of HR or the hand-operated switch HA.

The two main transformers have the same number of steps each, but corresponding steps are switched in consecutively, and the potential of the neutral point is then adjusted to an average value by means of the compensating coil AS.

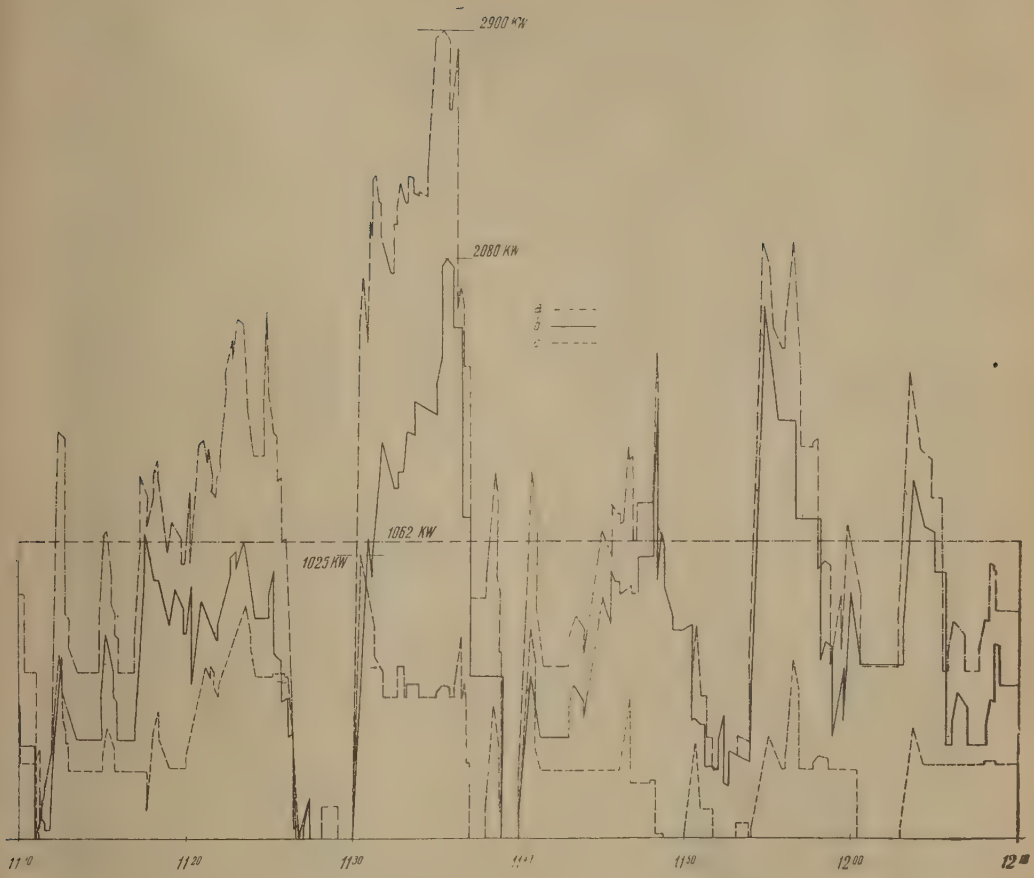
By this means (as long as both motors are working) eight instead of four running positions are obtained. A part of the exciter winding is distinct for the two directions of travel (this is an arrangement patented by the Siemens-Schuckert Werke), and the switches *v* and *r* serve to connect up the exciter windings according to the direction of travel. A further notable feature relates to the controller FS which, before starting, must be moved one step backwards. This causes the auxiliary drum W to rotate against the pressure of a spring until it becomes locked by the catch *z*. It then remains in this position during the further movement of the controller handle, but is subsequently released by NR, whereby all the auxiliary circuits are opened. The various interlocking devices between the switches are omitted in the diagram.

For braking purposes, there are two sets of electrically-driven air pumps, corresponding to the small and large ejectors in steam locomotives.

General traffic data.

The gross train weights with steam traction were 50 tons (49·2 English tons) for passenger trains and 105 tons (103·3 English tons) for goods trains. In the case of electric traction, it is intended to adhere as closely as possible to 100 tons (98·4 English tons) for normal trains of all classes; this is a load that can just be dealt with by one locomotive.

While the journey with steam traction occupied 4 1/2 hours, the *schedule time* with electric traction is to be 2 3/4 hours in the case of express trains, and 3 1/4 hours in the case of or-



a. . . = At power station I in Wienerbruck.

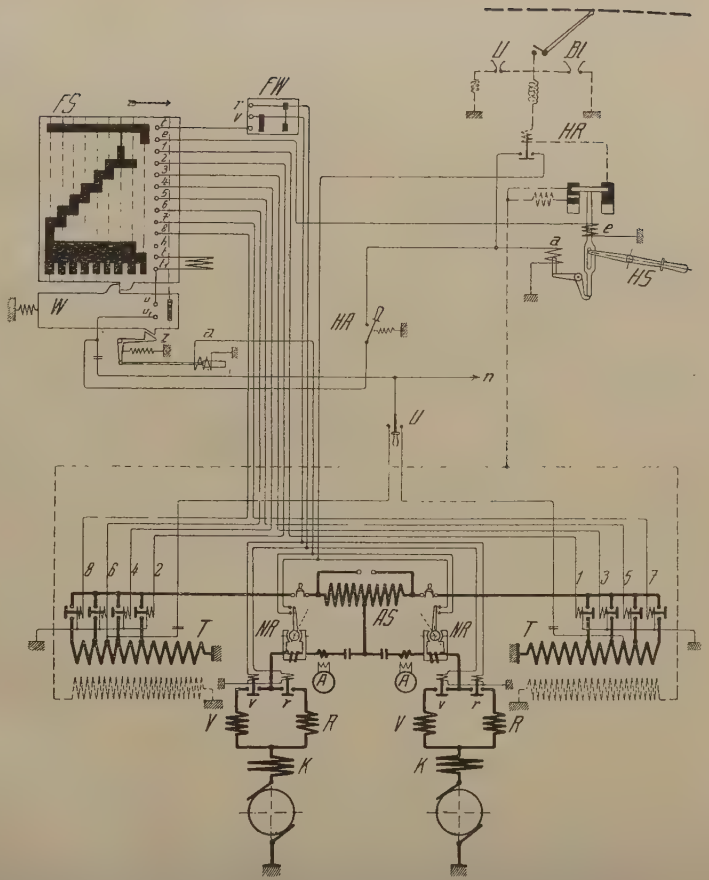
b. . . = At the 6,000 volt feeding point in Wiener-Bruck (at kilometre 7·40).

c. . . = At the 25,000/6,000 volt sub-station in Kirchberg on the Pieloch (at kilometre 31·3), excluding the loss in the transmission lines.

	At the current collectors calculated for power station I.	At power station I, excluding the loss in the transmission.
Maximum load (six trains on the line)	2,900 kilowatts.	3,900 kilowatts (4,300 kilovolts-ampères at a power-factor = 0·9).
Average load during the hour of heaviest service (from 11^{10} to 12^{10}) . .	1,062 kilowatts.	1,500 kilowatts.
Ratio of loads	2·73	2·60

Fig. 35. — Energy consumption, measured at the current collectors.
Saint-Pölten-Mariazell-Gusswerk line.

Bl. . . . = Lightning arrester.
U . . . = Protective device against excess voltages.
HR . . . = High-voltage } Maximum relays.
NR . . . = Low-voltage }
HS . . . = Hand-operated switch.
HA . . . = Low-voltage hand-operated switch.
e, a . . . = Solenoids for switching in and out.
T . . . = Main transformer.
AS . . . = Equalising coil.



V, R, K. = Excitation windings for forward and backward direction of travel and compensation windings.
v, r . . . = Switch for *V* and *R*.
U . . . . = Change over switch.
n . . . . = Connection for the heating and the lighting of the train and for the pump motors.
FS . . . = Controller.
W. . . . = Auxiliary drum of *FS*.
FW . . . = Reversing switch.

Fig. 36 — Diagram of connections of the locomotives. — St.-Pölten-Mariazell-Gusswerk line.

dinary passenger trains; these times, however, are not the lowest possible.

Shunting is to be done exclusively by electric locomotives; a few small accumulator locomotives are to be acquired for the main station at St. Pölten (and possibly for the station at Mariazell also) and for line inspection purposes and auxiliary trains, but ordinary locomotives are to be used for all other shunting purposes.

Steam locomotives will still be used on the Ober-Grafendorf-Mank-Gresten branch line, and they can be used to assist on the electric portion of the system when necessary.

On the 1 May 1907, the originally short branch line in the direction of Mariazell was extended to the latter place and the traffic has continuously and rapidly increased since then.

At that time the service was performed exclusively by steam locomotives. *In 1907*, 532,000 passengers were carried (corresponding to 20,762,000 passenger-kilometres [12,901,091 passenger-miles] and about 9,000,000 ton-kilometres [5,682,150 English ton-miles]), while the figures for the goods traffic were 7,328,000 net ton-kilometres (4,481,550 net English ton-miles), and about 11,000,000 ton-kilometres (6,944,850 English ton-miles). Altogether, therefore, the gross ton-kilometres amounted to 20,000,000 (12,627,000 English ton-miles). There were 2,704 passenger trains, 1,616 mixed trains and 1,779 goods trains.

In 1908, the train-kilometres amounted to 510,000 (316,904 train-miles), corresponding to 30,000,000 gross ton-kilometres (18,940,500 English ton-miles). Passenger traffic increased by 15 per cent and goods traffic by 50 per cent.

In 1909, twenty regular passenger trains and eight goods trains were in daily service. Four extra trains at the most were run in connection with the pilgrims traffic. Forty electric trains are contemplated for carrying on the future service.

Electric output. — The calculations are based on the assumption that the average efficiency between the bus bars at the power stations and the overhead wires is 87 per cent approximately, and that the average efficiency of the locomotives is 80 per cent approximately.

Figure 35 shows the load curves calculated for the power station during two hours and also the loads calculated for the secondary terminals of the transformers at the feeding points at Wienerbruck and Kirchberg on the Pielach; these loads are the sums of the energies measured at the bow collectors, no account being taken of the line losses between the collectors and power station I and the feeding points respectively. After adding the losses, the maximum load at power station I during the time in question was found to amount to 3,900 kilowatts, the average load during one hour being 1,500 kilowatts; the ratio of maximum to average load is therefore 2·6.

Price of current for the railway. — The agreement between the supply authority and the railway fixes the price per kilowatt-hour (measured at the low-voltage terminals of the sub-stations) during the first five years of electric traction at 8 hellers up to 2,000,000 kilowatt-hours and 7 hellers per kilowatt-hour beyond this, and a payment corresponding to 2,000,000 units per annum is guaranteed. According to the calculations, the gross ton-mileage per annum will amount to 50,000,000 ton-kilometres (31,567,500 English ton-miles), and if 60 watt-hours are reckoned per ton-kilometre, the yearly consumption will be 3,000,000 kilowatts-hours. After five years, the agreement is to be revised, and the price for current is to be fixed at 8 per cent above cost.

Price of current for private consumers. — The public electricity works also supply current for station lighting and private purposes, and a few figures relating to the supply to private consumers will no doubt be of interest since they have a marked effect on the price of current for the railway.

It is intended to supply current to local authorities and private consumers on the Wienerbruck-St. Pölten section, on the branch line to

Gresten and on the St. Pölten-Krems section of the State railways; the supply to large consumers of current is estimated to amount to 1,800 horse power and that to local authorities and small private consumers to 1,600 horse power. The charge for current will vary very much, according to whether full use is made of the connection or otherwise, and whether the sub-stations and transmission lines are provided by the supply authority or the consumers. Generally speaking, however, the price to large consumers is to range from 220-160 kronen (£9.3*s.* to £6.13*s.* 1·2*d.*) per horse-power-year, while the price to small consumers is to be 25 hellers (2·50*d.*) per kilowatt-hour for lighting and 10 hellers (1*d.*) per kilowatt-hour for power.

Of the present consumers, the municipality of St. Pölten pays 5·2 hellers (0·519*d.*) per kilowatt-hour to a certain total demand and 7·2 hellers (0·719*d.*) per kilowatt-hour beyond this (with a guaranteed consumption equivalent to the total capacity of the connections for 4,000 hours, corresponding to 208 kronen (£8.13*s.*) per annum per kilowatt connection), a large firm pays 3·76 and 5·2 hellers (0·375*d.* and 0·519*d.*) respectively, with a guaranteed consumption equivalent to the total capacity of the connections for 5,000 hours (corresponding to 188 kronen [£7.16*s.* 5*d.*] per annum per kilowatt connected up), while several localities pay on an average from 10 to 14 hellers (1*d.* to 1·40*d.*) per kilowatt-hour for lighting and power.

Even if the power stations had only been built for supplying energy for the railway, the financial results would have been better than with steam traction; the results are of course considerably improved with extending the supply to lighting and power consumers.

Revenue account (electric traction). — The preliminary calculations showed that the traffic could not be further increased by steam operation, except by laying down a second track, and this was out of the question on the score of expense. Electric traction, on the other hand, promised reduced expenditure and increased receipts combined with higher speeds. For train-mileages of 600,000 and 750,000 kilometres (372,830 and 466,040 miles) per annum, the saving was estimated at 100,000 and 127,000 kronen (£4,160 and £5,282.4*s.*) respectively; these figures include interest on capital and sinking-fund charges.

The capital expenditure for the feeders and sub-stations is debited to the capital account of the power station. The calculated running costs with steam traction are based on the statistical information to date and were checked by M^r^ Heimpel, chief inspector of the Munich Lokalbahn-Aktiengesellschaft, who compared them with the results obtained on the Murnau-Oberammergau line, where similar conditions prevail.

The cost of haulage with steam traction is 97·5 hellers per train-kilometre (1*s.* 3·67*d.* per train-mile) according to the statistics referred to, or 95·2 hellers (1*s.* 3·30*d.*) according to M^r^ Heimpel, while the corresponding costs with electric traction under the same service conditions come to 79·9 hellers (1*s.* 0·84*d.*); these figures refer to a 100 ton (98·4 English tons) train. On this basis, the saving in the cost of haulage pure and simple is 208,200 kronen (£8,661.2*s.*), while the saving in traffic expenditure generally is 100,000 kronen (£4,160); these figures take no account of the additional saving due to the smaller number of motor coaches etc. in reserve and to the simplification in running the workshops.

The following particulars are taken from the original report on the expenditure and receipts of this railway, which was submitted in 1906 to the Landesausschuss of Lower Austria. The figures are based on twenty 100 ton trains (98·4 English tons) per diem, corresponding to 610,000 train-kilometres (379,043 train-miles).

a) *Costs with steam traction.*

	Kronen.	(£ s.)
Interest of 4 per cent amortisation on the twenty years basis (3·36 per cent) of the capital of 1,150,000 kronen (£47,840)	84,640	(3,521)
Fuel, lubricating and cleaning material; in the years 1903 to 1906 these costs amounted to 60, 45, 51 and 46 hellers per 100 ton-kilometres (9·869*d.*, 8·326*d.* and 7·51*d.* per 100 Engl. ton miles) calculated for the whole railway system, the average being 50 ½ hellers (8·244*d.*) by adding 20 per cent for the mountain section, the total comes to	369,660	(15,377.17)
(Mr. Heimpel based his calculations on a consumption of 24 kilograms of coal per train-kilometer, (85·15 lb. per train-mile) coal at 22 kronen per ton (18*s.* 7·17*d.* per English ton), and assumed 1,500 kronen (£62.8*s.*) per locomotive for lubricating and cleaning material; his total came to 337,800 kronen (£14,052.10*s.*) of which 322,800 kronen (£13,428.10.) were for fuel; at 4 ½ per cent the latter sum would correspond to a capital of 7,000,000 kronen (£291,200).		
Train staff: 12 drivers at 2,000 kronen (£83.4*s.*) each, 12 stokers at 1,200 kronen (£49.18*s.*) each, 13 guards at 1,500 kronen (£62.8*s.*) each and 14 conductors and brake men at 1,100 kronen (£45.15*s.*) each	73,300	(3,049.5)
Maintenance cost of locomotives; 7·3 per cent was assumed, this being the average during four previous years; for twelve locomotives working with superheated steam and costing 60,000 kronen (£2,496) each, this gives	52,600	(2,183.3)
(Mr. Heimpel assumed 12 hellers per train-kilometre (1·928*d.* per train-mile) and arrived at 73,200 kronen (£3,045.2*s.*)		
Sundry expenses connected with the train service	14,800	(615.14)
Total for steam traction	595,000	(24,752)

This sum corresponds to 97 ½ hellers per train-kilometre (1*s.* 3·67*d.* per train-mile) with trains weighing 100 tons (98·4 English tons) In previous years four to six small locomotives, costing 32,000 kronen (£1,331.4*s.*) each, were employed, and the cost per train-kilometre amounted to 35 hellers (5·624*d.* per train-mile), with 40-ton (39·4 English ton) trains.

b) *Costs with electric traction.*

Interest (4 per cent) and amortisation (on the twenty-five years basis) of the rolling stock costing 1,300,000 kronen (£54,080) equivalent to 6·4 per cent of the capital expenditure.	33,200	(3,461.2)
Ditto for the line equipment costing 1,640,000 kronen (£68,224) equivalent to 5·05 per cent of the capital expenditure.	82,820	(3,445.6)
Train staff: 17 drivers at 1,800 kronen (£74.18*s.*) each, 9 chief guards at 1,500 kronen (£62.8*s.*) each, 9 guards and brake men at 1,100 kronen (£45.15*s.* each	54,100	(2,250.11)
Electric energy (4·1 kilowatts-hours per train-kilometre (6·6 kilowatts-hours per train-mile), with an extra of 20 per cent shunting and up gradients) at 5·5 hellers (0·548*d.*) per kilowatt-hour	165,555	(6,882.2)
Overhead line material	10.000	(416.0)
Maintenance cost of locomotives, reckoned at 8·6 hellers per train (100 tons (98·4 English tons) per kilometre	52,460	(2,182.7)
Maintenance of overhead wires (2 per cent of 400,000 kronen (£16,640) for the trolley wire and 1 per cent of 990,000 kronen (£49,500) for the remainder)	17,000	(744·13)
Sundry traffic expenses	20,965	(872.3)
Total for electric traction	487,000	(24,350)

This gives 79·8 hellers per train-kilometre (1*s.* 0·82*d.* per train-mile) with trains weighing 100 tons (98·4 English ton). Steam traction was commenced on the St. Pölten-Kirchberg section on 4 July 1898 and on the branch line to Mariazell on the 15 July 1907. Experiments with electric traction were carried out in 1909, and in May of this years several pairs of electric trains are to be put in service.

APPENDIX III.

Description of electric full-gauge railways for which plans have been prepared.

Plans for the Trieste-Opcina line and for the shunting yard and Trieste (State railways).

The state railway line Trieste-Opcina is single track and 15·6 kilometres (9·7 miles) long. It rises gradually from a point 2·5 metres (8 ft. 3 in.) above sea level to Opcina, 310·4 metres (1·018 feet) above the sea, the average gradient being 2·7 per cent. The line terminates in Trieste in a goods and shunting yard which is 1·8 kilometres (1·11 miles) long and has twenty-three tracks at its widest point. 78 per cent of the total length of the line lies in gradients of 2·1 per cent and over. The radius of the sharpest curves is 250 metres (12 1/2 chains). There are only two stopping places Rozzol & Guardiella, which interrupt the steady incline. The length of the through track is 16,450 metres (10 miles 390 yards), that of the side tracks 30,459 metres (18 miles 1,631 yards). The total length of the tracks is therefore nearly three times the length of the route. The five single-track tunnels have a combined length of 3,904 metres (2 miles 750 yards) and they are damp throughout, and in parts even wet. The rails are 12·5 metres (41 feet) long and weigh 35·6 kilograms per metre (71.7 lb. per yard).

As the plans are in many respects very instructive and typical, the most important particulars of the plans, which have been prepared by the writer, are given below.

Electric operation is to be introduced for two reasons, viz. to improve the ventilation in the tunnels, which is very bad at times, and to enable the expected increase in traffic to be dealt with.

The Trieste-Opcina line has been running for two years, but it is only since the opening of the Tauern railway in July, 1909, that the traffic has gradually grown to its full value, chiefly due to the through traffic on the Salzburg-Villach-Görz-Trieste route. Even in 1908, the single-track line with its severe gradients and long distances between block signals (up to 4·6 kilometres [2·85 miles]) was fully loaded, and the expected increase in traffic in the near future can no longer be carried on economically, if at all, by steam traction. The limit is reached at present with two pairs of express trains, seven pairs of ordinary passenger trains and ten pairs of goods trains.

The chief reason for this limitation is the very bad natural ventilation in the single-track tunnels (which lie in severe gradients and curves) when the meteorological conditions (Bara) are unfavourable. In these cases, the smoke clouds stagnate in the tunnels, and when oil is used as fuel, poisonous gases and an intolerable quantity of smoke at high temperature are produced. This is especially the case with the locomotives employed to push the train at the rear end. Careful tests in 1907 have shown that the quantity of carbon dioxide and carbon monoxide and smoke, may temporarily accumulate to an intolerable extent. In the Revoltella tunnel, which is 1,270 metres (1,389 yards) long and lies in a 2·2 per cent gradient, the temperature may rise to 42° C. (108° Fahr.); the lamps in the drivers' cab frequently fail. In these tunnels, the rear locomotive acts as a loose-fitting plunger and throws the smoke on to the drivers cab. In order to ensure a reliable steam service under the worst climatic conditions, it would be necessary to keep spare locomotives in readiness so as to be able to haul the goods locomotives through the tunnels at a good speed. Such expedients (as also the provision of costly ventilating arrangements) would, however, only increase the capacity to that of an equivalent open line. Electric traction, on the other hand,

will not only remove the smoke nuisance, but will also increase the carrying capacity of the line to a considerable extent, thus justifying the additional capital outlay.

In the year 1908, 6,970 tons (6,860 English tons) were hauled per diem on an average, while the locomotive-hours amounted to 35,300. The future volume of traffic, taking the newly-opened Tauern railway into consideration, is estimated as follows :

In the near future : 12,700 tons (12,500 English tons) per diem (averaged over a whole year) with 16,600 tons (16,338 English tons) as a maximum; later on 21,300 tons (20,964 English tons) which represents the upper limit; in the immediate future, the traffic is estimated to amount to 68,550,000 gross ton-kilometres (43,279,043 English ton miles) (of which 73·4 per cent falls on goods trains), 222,700 train-kilometres (138,381 train-miles) and 70,000 train-hours.

The trains assumed are five pairs of express trains, seven pairs of ordinary passenger trains and twelve pairs of goods trains at most, making altogether forty-eight trains daily (twenty regular trains and four extra trains).

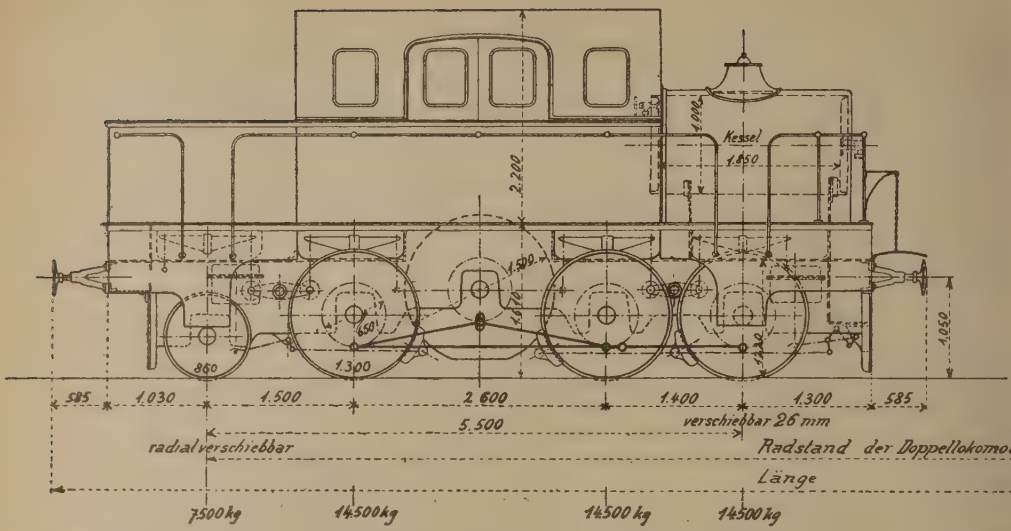
The train weights will be as follows : Saloon-trains, 130 to 180 tons (128 to 177 English tons); express trains, 150 to 280 tons (148 to 275 English tons), passenger trains, 150 to 340 tons (148 to 335 English tons) and goods trains first 550 tons (541 English tons), and after completion of the electric system beyond Opcina, 700 tons (689 English tons).

The increase in carrying capacity is mainly obtained by increasing the schedule speeds, without exceeding the permissible limit of 50 kilometres (31·0 miles) per hour which is fixed by considerations relating to the track. By increasing the speed of trains with passenger carriages to 70 kilometres (43·5 miles) per hour and that of goods trains to 40 kilometres (24·8 miles) per hour on the straight level, the speed on the 2·7 per cent gradient will be 35 kilometres (21·7 miles) per hour for express and passenger trains (and 40 kilometres [24·8 miles] per hour when time has to be made up) and 25 kilometres (15·5 miles) per hour for goods trains; this represents an average speed for the up-journey of 50 and 25 kilometres (31·0 and 15·5 miles) per hour respectively. The saving in time alone which is thus effected amounts to 19·35 per cent for express and passenger trains and 50 per cent for goods trains on the up-journey and 8·5 and 28 per cent respectively on the down-journey. Without these increased speeds it would not be possible to deal with the forty-eight trains which are expected to be necessary in the future.

All classes of trains are to be drawn by the same type of locomotive with three driving axles and one pony axle; the latter is necessary on the down-journey for speeds above 35 kilometres (21·7 miles) per hour on account of the permanent way. Figures 37 and 38 illustrate two designs for the mechanical part, which were worked out by Ministerialrat Gölsdorf of the railway administration. Figure 39 and 40 show the graphic time table for two typical train journeys with single-phase locomotives.

The acceleration on straight level stretches is assumed to be 0·25 metre (9 $^{13}/_{16}$ inches) per second for trains conveyning passengers and 0·15 metre (5 $^{15}/_{16}$ inches) per second for goods trains. The trains will start promptly on the maximum gradient. The average acceleration on the level will be 0·2315 metres (9·1143 inches) per second for trains with passenger coaches (a speed of 50 kilometres [31·0 miles] will be attained after 440 metres [1,443 feet] have been covered), and 0·1396 metres (5·4961 inches) per second for goods trains, corresponding to a speed of 40 kilometres (24·8 inches) per hour after 470 metres (1,542 feet) have been covered.

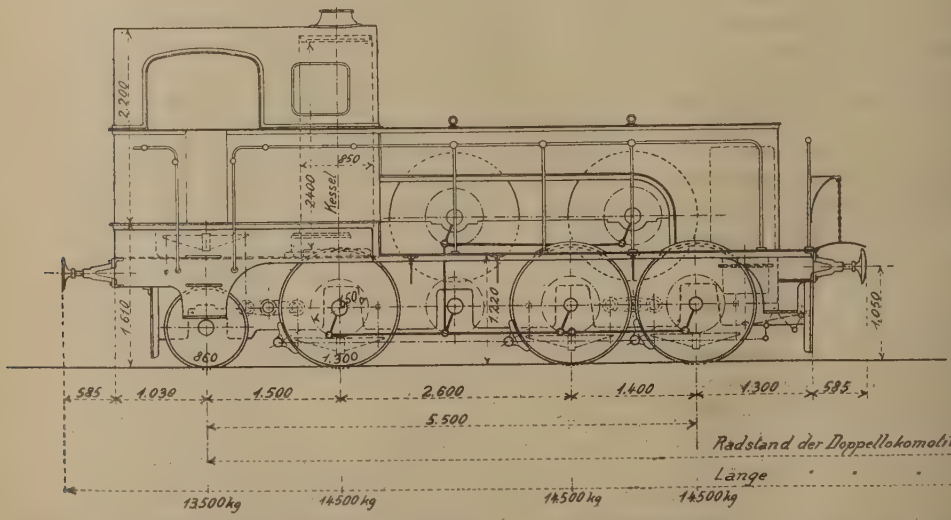
The tractive effort at the periphery of the driving wheels is for express and passenger trains 15·6 tons (15·35 English tons) (11·9 tons [11·7 English tons]) at starting and at most 13·4 tons (13·2 English tons) (10·2 tons [10·0 English tons]) during running, and for good trains 29·9 tons (29·4 English tons) (11·5 tons



Weight of locomotive, empty . . . 49,000 kilograms (108,030 lb.)
— — in service. . 51,000 — (112,440 —)

Weight available for the electric equipment . . . . . 20,000 kilograms (44,090

Fig. 37. — Design of electric locomotive with one motor. — Trieste-Opcina line.



Weight of locomotive, empty. . 55,000 kilograms (121,250 lb.)
— — in service. 57,000 — (125,660 —

Weight available for the electric equipment. . . . . 25,000 kilograms (55,120 lb.

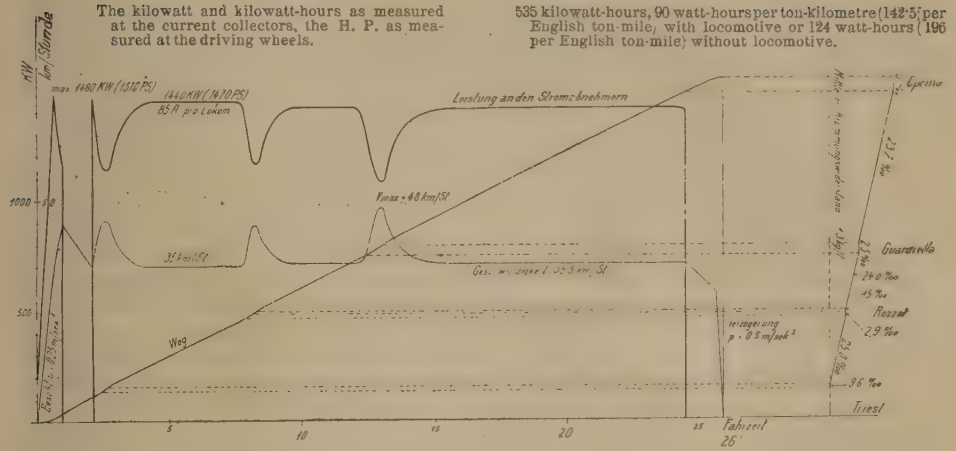
Fig. 38. — Design of electric locomotive with two motors. — Trieste-Opcina line.

Explanation of German terms: Radial verschiebbar = Radial play. — Verschiebbar 26 mm = 26 millimetres (1 inch) play. Radstand der Doppellokomotive = Wheel-base of double locomotive. — Länge = Length. — Kessel = Boiler.

Two locomotives . . . 106 tons (104·32 English tons).
Train . . . . . 280 — (275·5 —).

The kilowatt and kilowatt-hours as measured at the current collectors, the H. P. as measured at the driving wheels.

535 kilowatt-hours, 90 watt-hours per ton-kilometre (142·5 per English ton-mile) with locomotive or 124 watt-hours (196 per English ton-mile) without locomotive.

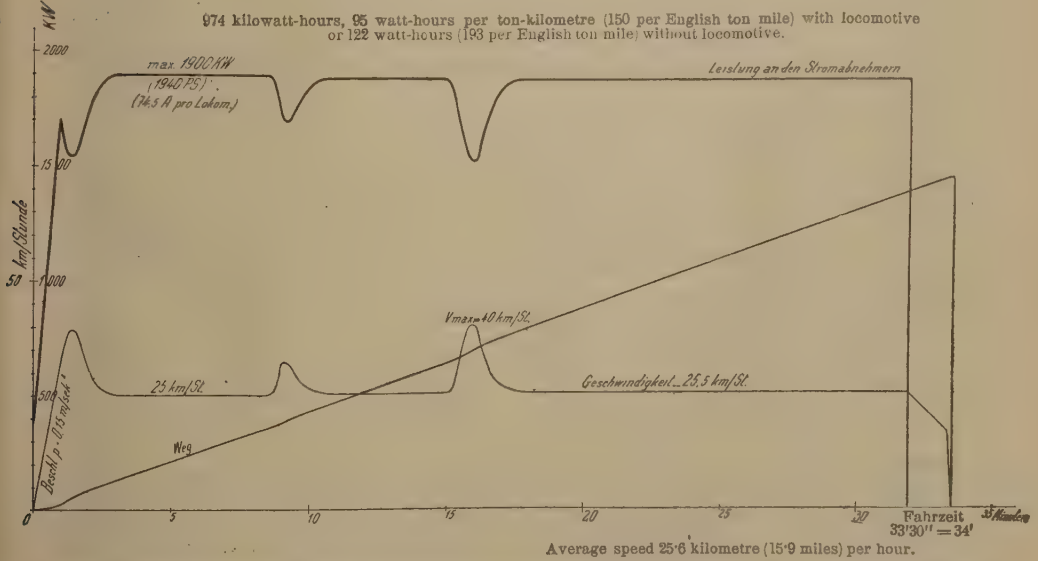


Average speed : 36 kilometres (22·4 miles) per hour.

Fig. 39. — Speed and power curves for an express or passenger train from Trieste to Opcina (regular service run).

Three locomotives . . . 159 tons (156·5 English tons).
Train . . . . . 550 — (541 —).

974 kilowatt-hours, 95 watt-hours per ton-kilometre (150 per English ton mile) with locomotive or 122 watt-hours (193 per English ton mile) without locomotive.



Average speed 25·6 kilometre (15·9 miles) per hour.

Fig. 40. — Speed and power curves for goods or express goods trains from Trieste to Opcina (regular service run).

Explanation of German terms : Beschl. = acceleration. — pro Lokom. = per locomotive. — Km St. = Km per hour. — PS. = H. P. — Leistung an den Stromabnehmern = Energy at the current collectors. — Geschwindigkeit = Speed. — Mittlere Krummungswiderstand = Average curve resistance. — Verzögerung = Retardation. — Fahrzeit = Schedule time. — Triest = Trieste. — Minuten = Minutes.

[11·3 English tons]) at starting and 27·3 tons (26·8 English tons) (10·5 tons [10·3 English tons]) during running. The figures in brackets give the corresponding pulls at the foremost coupling.

The weight per driving axle of the locomotives is 14·5 tons (14·3 English tons). Trains with passenger coaches weighing up to 200 tons (197 English tons) can be hauled by a single locomotive; goods trains will always be drawn three locomotives, and later on by four locomotives when the 700 ton trains are introduced.

The maximum and normal train loads are based on an adhesion of $\frac{1}{5{\cdot}5}$ and $\frac{1}{6}$ respectively.

Trains conveying passengers are equipped throughout with automatic vacuum brakes which are almost exclusively so adjusted as to give the maximum possible braking effect short of slipping of the wheels; the increased speed of goods trains has made it necessary to increase the braking effect slightly.

As electric locomotives have no tender, the braking effect is lessened by an amount corresponding to the adhesion of such a tender; in order, however, to obtain approximately the same safety as hitherto, it is intended to fit the pony wheels with brakes as well, but these are only to be applied when the brakes on the driving wheels are fully applied. While the reserve brake weight (represented by the tender) amounts to about 17 per cent in the case of steam traction, it will be about 14 per cent in the case of electric traction.

The locomotives are to be lighted by electricity and the carriages as heretofore by oil-gas. It is intended to heat the trains by steam, produced in electrically-heated boilers on the locomotives. The steam for heating before the train commences its up-journey is to be obtained from stationary boilers. Heating can be dispensed with during the short down-journeys.

Two alternative motor equipments for the locomotives have been suggested, *viz.* two motors and one motor only. Assuming a stoppage of ten minutes at the termini, the requisite continuous tractive effort and continuous motor output per 4-axle locomotive are as follows: For trains with passenger coaches (35 kilometres [21·7 miles] per hour), 340 tons (335 English tons), 4,090 kilograms (9,017 lb.) and 530 horse power respectively; for goods trains (25 kilometres [15·5 miles] per hour), 550 tons (541 English tons), 4,750 kilograms (10,472 lb.) and 450 horse power respectively. The single-phase motors, which must be capable of developing the larger of the two tractive efforts, must have a continuous rating of 450 horse power per locomotive at the slow speed and 616 horse power at the high speed. On the assumption that the continuous tractive effort is only 50 per cent of the tractive effort which could be developed by the motors for one hour, the capacity of the motors would have to be 1,060 and 880 horse power respectively on the one hours' rating. Assuming, further, that the maximum possible tractive effort is only 35 per cent higher than the tractive effort on the one hours' rating, the maximum efforts come to 11,040 and 12,830 kilograms (24,339 and 28,285 lb.) respectively and these are values which would cause slipping of the wheels under all conditions. The motors are ample, as they are not even called upon to develop their full tractive effort (on the one hours' rating) during the up-journey.

The motor capacity will, however, not be decided upon with reference to the above figures, but will be based on calculations for a long and steep up-gradient, so that the locomotives can be used on any part of the Austria-Hungarian railway system. For the present, eighteen locomotives will be required, and in order to gather experience, it is proposed to acquire single-phase locomotives of various types.

A characteristic feature of the overhead installation is the extraordinary length of the tracks compared with the length of the route (this length is for steam traction 35·2 kilometres (21·9 miles) or 214 per cent of the length of the route, and for electric traction 46·9 kilometres (29·1 miles) or 285 per cent of the length of the route, and the very high peak loads.

The latter depend on the number of trains (when delays occur) simultaneously on their up-journey. It must be assumed that in the worst case there will be three trains of a total weight of 1,380 gross tons (1,358 English tons); if it should be found possible to limit the number of up-trains at any one time to two by suitable arrangement of the time table, then the peak load could be considerably reduced.

The effect of this is shown in the following table, in which are tabulated the horse power at the shafts of the steam or water turbines in a power station which is assumed to be situated near Trieste.

No.	—	Trains.	Shunting.	Total.
1	Average horse power during twenty-four hours, taken over a whole year	935	610	1,545
2	Ditto on the day of maximum traffic	1,181	724	1,905
3	Three trains simultaneously on the up-journey . . . Maximum load. . .	9,754	1,186	10,940
4	Three trains simultaneously on the up-journey . . . $\left(\frac{3}{1}\right)$	10·4	2·0	7·1
5	Three trains simultaneously on the up-journey . . . $\left(\frac{3}{2}\right)$	8·3	1·6	5·7
6	Two trains simultaneously on the up-journey . . . Maximum load. . .	7,264	1,186	8,450
7	Two trains simultaneously on the up-journey . . . $\left(\frac{6}{1}\right)$	7·8	2·0	5·5
8	Two trains simultaneously on the up-journey . . . $\left(\frac{6}{2}\right)$	6·1	1·6	4·4

It follows that by a slight readjustment of the time table (so as to avoid the simultaneous running of three trains on the up-journey, which might otherwise occur once or twice a day), it would be possible to reduce the peak load by 2,500 horse power.

It is not easy to reduce the peak loads by splitting up the goods trains into smaller units on account of the long block sections and also because it is necessary to despatch the steam-operated trains which arrive in Opcina with the least possible delay. A more efficient remedy would be to transfer the shunting operations to Opcina.

The transmission lines were calculated for an average line voltage of 10,000 volts and a frequency of from 14 to 16 $^2/_3$ cycles per second. The calculations show that the feeders must be proportioned with reference to drop in pressure; this is due to the high line voltage adopted.

Figure 41 shows the drop in voltage in the most unfavourable case, *i. e.* when four trains are simultaneously on the up-journey. The assumed feeding point is at A, to which current is supplied from the power station at Z, 2 $^1/_2$ kilometres (1·55 mile) distant). The connection between Z and A can be made by cable or overhead line. The maximum drop in voltage amounts to 24 per cent in the case of three trains and to 20·4 per cent when only two trains are on the up-journey, and to 21·9 per cent and 25·3 per cent (with two trains) when the feeder between A-B and C-D respectively is interrupted. These figures are based in all cases on a maximum load of 750 kilowatts for shunting purposes in Trieste.

The maximum current density in the line wires is 3·16 ampere per square millimetre (0.00489

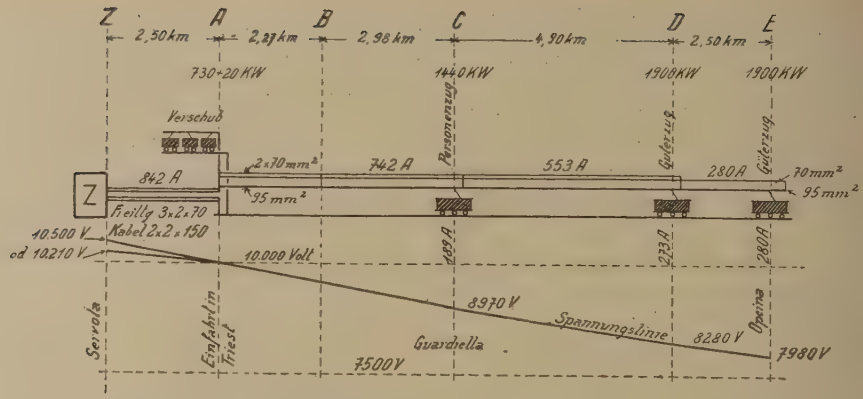


Fig. 41. — Diagram to determine maximum drop in voltage on the Trieste-Opcina line.

Explanation of German terms : Kabel = Cable. — Freiltg. = Overhead line. — Verschub = Shunting. — Einfahrt in Triest = Entrance in Trieste. — Spannungslinie = Voltage curve. — Personenzug = Passenger train. Güterzug = Goods train.

ampere per square inch), and in exceptional cases 5·9 ampere per square millimetre (0.00914 ampere per square inch).

Designs for the Prague-Nusle (-Smichow) Railway.

The lines to be electrified form a triangle (with few gradients) with three extensions to Prague (Kaiser Franz-Josefs station), Nusle and Smichow respectively. Of these, the Prague-Nusle section (2 1/2 kilometres [1·55 miles] long) has the greatest traffic and forms a part of the Prague-Vienna main line. The traffic on the Prague-Smichow line (3·6 kilometres [2.2 miles] long) is less heavy, and the goods traffic on the Smichow-Nusle line is light; the two last-mentioned lines are in the direction of Pilsen.

The maximum gradient, which occurs at a single point near the Königliche Weinberge station, is 1·1 per cent. Between this station and the main station at Prague there is a tunnel (1·2 kilometre [0.74 mile] long) situated in a gradient of 0·3 per cent. The first switches of the main station at Prague are situated in the near end of this tunnel.

The chief reasons for adopting electric traction were technical and not commercial.

To begin with, it was desired to reduce the smoke-nuisance in the tunnels, which was considerable, seeing that 150 trains and about 60 empty-running locomotives passed through the tunnel per diem; this smoke caused an increase in the working costs and hampered the shunting operations on the Prague side. It was also desired to do away with a large number of the journeys of empty-running locomotives between the station at Prague and the coal depot Nusle; this will permit of an increase in the traffic and will enable the locomotives (which during heavy traffic are sometimes detained for three hours at the Prague station before they can return to Nusle) to be more fully utilised It was further desired to avoid the inconvenience of having to light-up the passenger coaches before entering the tunnel and extinguishing the lights after the tunnel had been passed; this inconvenience is to be remedied by the installation of powerful incandescent lamps in the tunnel, which will be alight during the time that passenger trains are run. Moreover, the elimination of the smoke-nuisance will effect a saving

in the painting (which is expensive) of the large railway station at Prague Finally, it is intended to supply current from the proposed railway power station to all the State-owned stations in Prague for lighting purposes; at the present, such current has to be purchased from the municipality of Prague at the price of 19 hellers (1·89*d*) per kilowatt-hour. Assuming that current could be generated at the new station at a cost of 10 hellers (0·998*d*.) per kilowatt-hour, the total saving would amount to over 100,000 kronen (£4,160) and this alone would probably more than counterbalance the additional cost due to the introduction of electric traction.

It will be gathered from the above that more than two hundred trains (including empty-running locomotives) pass daily through the tunnel, while only about twenty goods trains run on the Smichow-Nusle section. The gross tons dealt with daily on the Nusle-Prague section amount to 3,830 (3,770 English tons) for trains conveying passengers and 22,000 (21,652 English tons) for goods trains; the corresponding figures for the Prague-Smichow section are respectively 7,330 and 700, and for the Nusle-Smichow section 11,000 for goods trains.

The yearly consumption of energy, measured at the high tension feeding, will amount to the following:

For train haulage.	2,200,000	kilowatt-hours.
For shunting . . .	5,100,000	— —
For station lighting	1,300,000	— —
Total. . . .	8,600,000	kilowatt-hours.

The maximum load for train haulage alone will be 3.230 kilowatts, but it is found (as was similarly the case in the Trieste-Opcina line) that if the present time table were adhered to, the maximum demand would reach 4,000 kilowatts at one certain time per day. This, however, can be avoided by slightly altering the schedule times of a single train (without hampering the goods service), thus reducing the capital expenditure considerably.

Otherwise, the present time table and likewise the weights of the trains will be adhered to. Express trains weigh up to 300 tons, passenger trains occasionally up to 650 tons (640 English tons) and goods trains very often 1,000 tons (984 English tons). Altogether, nineteen locomotives will be required, of which five will be used for shunting, while four will be kept in reserve or will be in the shops for overhauling. As will be seen from the above, the shunting operations in the three stations (120,000 hours per year) will require the larger part of the energy.

Designs for the Znaim-Raabs (Thayatal railway) (1).

This line is to have a length of 60 kilometres (37 miles), full gauge, with a maximum gradient of 3 per cent. It is suggested to run ten passenger trains (with motor coaches) and four goods trains (drawn by locomotives) per day. The motor coaches are to hold fifty passengers and they will be coupled to not more than two trailers holding fifty passengers each. The speed is to be from 50 to 60 kilometres (31 to 37 miles) per hour on the level and 30 kilometres (18·6 miles) per hour on the 3 per cent gradient. The locomotives (with a train weighing 250 tons [246 English tons] gross) are to run at 30 and 20 kilometres (18·6 and 12·4 miles) per hour respectively. It is intended to acquire four four-axle motor coaches and two locomotives, with a motor capacity of from 250 to 300 horse-power each. These are to deal with a yearly traffic amounting to 400,000 passenger-kilometres and 1,500,000 gross ton-kilometres (248,550 passenger-miles and 947,025 English ton-miles) (goods service).

It is proposed to employ single-phase current at from 5,000 to 7,500 volts at a low frequency, and no sub-stations are contemplated.

Energy is to be obtained from two water-power stations (at Vöttau and Frain respectively) with

(1) *Elektrotechnik und Maschinenbau*, 1907, p. 429, and 1908, p. 283.

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large water reservoirs and a head of 20 metres (65 ft. 7 in.). From one third to one-half of the total output (corresponding to 3,000 horse-power for ten hours per day) is to be used for the railway, while the remaining power (in form of single-phase current at 50 cycles per second, produced in separate generators) will be supplied for lighting and power purposes. A separate steam plant of 1,000 horse-power capacity is to be erected in Vöttau as a reserve. Both power stations are to be connected in parallel by means of double transmission wires. Assuming a total output of 5,000,000 kilowatts-hours per annum, the price of the current for power is calculated to come to 15 hellers (1·50*d.*) per kilowatt-hour.

APPENDIX IV.

Detailed list of questions relating to question VIII.

A. — General.

1. Are you contemplating the introduction of electric traction, on an extensive scale, on main lines with a view of utilising in a systematic manner available water powers, coal and peat deposits or other material of lower calorific value?

What reasons, from the technical point of view, have induced you to adopt electric traction?

Do the electric trains or cars on the electrified portions of your railway system deal with passenger and goods traffic, and more particularly, is the electric service so organised as to be able to deal with a heavy goods traffic in an economical manner?

Are the conditions for the further extension of electrical working favourable, or are there considerations which point to the fact that the extensions will only be gradual?

2. Have portions of your railway system been adapted for electric traction for experimental purposes in order to enable you to draw conclusions with regard to a more extensive introduction of electric traction?

What kind of current was used for these experiments; were the latter successful?

When were the experiments carried out, and when was the regular service commenced?

Has electric traction proved to be equal to steam traction as regards safety and economy?

3. Were comparative investigations carried out between continuous current, three-phase and single-phase current, or combinations of different kinds of current, for the purpose of deciding the kind of current to be used?

Which kind of current have you decided on?

Have you decided on a definite voltage and frequency for the overhead line as standard for the general introduction of electric traction, and if so, what values for voltage and frequency have you adopted, and what were your reasons for selecting these values?

4. Question VIII (IV of section 2) has reference to investigations on the comparative costs for the various kinds of current.

Kindly, therefore, place at our disposal, for the purpose of publication, your comparative calculations concerning the capital costs and running costs, as also the result of your deliberations regarding the advantages and disadvantages of the various kinds of current and the reasons which induced you to select the kind of current adopted.

5. The answers to questions should, wherever possible, also extend to railways for which electric traction has been definitely decided on and for which the particulars have been worked out.

6. Please append any interesting information on points which have not been touched upon in the questions.

7. In case existing or contemplated installations have been described in the technical press, kindly give the references to such publications, or send reprints of the articles.

B. — Constructional data.

8. — Which main line railway stations are connected by the electric railway?

What is the length of the railway (in miles); the gauge (in feet and inches), and the number of tracks?

9. What is the maximum gradient and what is the length of this maximum gradient (in miles)?

Has the railway line many curves?

What is the radius of the sharpest curves (in chains)?

What is the difference in altitude (in feet and inches) between the termini of the railway?

Can you supply us with the profile of the line, and a diagram of the curves?

10. What is the maximum permissible weight per wheel for the rails employed, and what is the maximum permissible speed (in miles per hour)?

11. What is the weight of the rails per yard? How long are the rails?

C. — Electric power station.

12. What is the relative position of the power station with respect to the railway line?

(Please append sketch giving distances, if possible.)

13. Is the electric energy for operating the railway produced in your own power station, or is it purchased from an outside station; how many lines are supplied with current from the one power station?

14. State whether water power or heat engines are employed for producing the current.

Water-power plants.

15. What water power is used? (Name of river).

What quantity of water (in cubic feet per second) is available in the different months and what is the effective head (in feet)? Can you supply a table or curve showing the available quantity of water throughout the whole year?

16. What special advantages induced you to decide on water power? Is there a natural or artificial reservoir? If so, how many cubic feet of water does the reservoir hold, and how large is its capacity expressed in kilowatt-hours?

17. What is the available output, measured in effective horse-power at the turbines?

18. How many water turbines or water wheels are installed; of what design are they, and what is their output (in horse-power) and speed (in revolution per minute)? What kind of governors are employed and what are their regulating properties?

19. What is the total output of all the generators (in kilowatts)? Is each generator provided with its own exciter, or are exciters employed for feeding the generators in groups? Is it necessary, on account of the railway's motors, to fulfil special conditions as regards constancy of the voltage, and if so, what means (compound winding, Tirrill regulators) are employed to meet this requirement?

20. What was the capital cost (per kilowatt installed in the power station) for the buildings, turbines and dynamos including switch gear?

21. Are the water turbines sufficient for maintaining the service, or are heat engines installed to give assistance? Of what type are they and what is their output? How often, and for what reasons, must they be used? (Ice, low water.)

See also question No. 30.

Power stations employing heat engines.

22. Are steam engines or gas engines employed?

23. How many boilers are in service?

(Type, method of stoking, heating surface, grate area, pressure, water converted into steam, efficiency.)

24. How many gas producers are in service? (Type, capacity.)

25. What material is used as fuel, and what is its calorific value?

26. What special reasons induced you to adopt this fuel? Was the situation selected for the power house influenced by the nature of, or the method of producing, the fuel?

27. Are special means provided for increasing the results obtained from the fuel? (Superheaters, re-heaters, economisers.)

28. State the number of heat engines installed, their type, output in horse-power and speed in revolutions per minute? What conditions do they fulfil as regards regulation?

29. What is the output of the separate dynamos and of all the dynamos (in kilowatts)? Has the low frequency given rise to difficulties in the design of the dynamos?

30. Are accumulators provided in the power house or sub-stations to eliminate the fluctuations in the load, and, if so, what is the number of cells employed and what is the capacity of the batteries in ampere-hours and kilowatt-hours?

What is the efficiency taken over a whole year, *i. e.* the ratio of the output of the battery (in kilowatt-hours) in a year to the input (in kilowatt-hours) during the same period? Are special auxiliary machines installed to assist the inter-action between the dynamos and the battery, and, if so, what is their capacity?

What results have been obtained with the storage batteries? What is the average life of the cells? Are the batteries maintained by an accumulator firm at a fixed sum for a number of years, or by your own men?

Question No. 30 should also be considered as complementary to question No. 21 relating to water-power plants, and should be replied to in this connection also.

31. What is the capital cost of the electric station, and what are the capital cost (per kilowatts installed) of the buildings, machinery and electric equipment respectively?

32. What were the chief objects kept in view in the design and arrangement of the electric connections and switch gear? Please send, if possible, a diagram of connections showing the arrangement of the machines and apparatus, and the system of distribution.

This question should also be answered for water-power stations.

D. — Transmission.

33. Which form of current is employed for transmitting the electrical energy from the power house to the points where it is consumed? Voltage. Frequency.

Is the current converted from one form to another at the points of consumption, or is it merely transformed in pressure? (Sub-stations with running machinery and accumulator batteries, transformer sub-stations.)

Feeders.

34. At what points of the railway line (mile posts) are the feeders connected up? State the lengths and cross sections of the various feeders, and the average loads in kilowatts which are transmitted to the different feeding points.

For what copper losses and voltage drops were the feeders calculated?

State the output of the transformers, motor generators, converters.

35. Are the feeders in the form of underground cables or overhead wires? Are the overhead wires supported by wooden poles, iron poles or poles of armoured concrete? At what intervals are the poles placed? What is the form of the insulators employed? How are they fixed? Are the insulators carried on cross pieces of iron or wood?

36. What arrangements are provided for safeguarding the overhead lines from excess voltages, and what degree of success has been attained?

What arrangements have been made in connection with the fusing of the overhead wires due to an "earth" caused by breakage of an

insulator or other breakdown of the insulation?

37. State the capital cost of the feeder line per mile, and of the transformer sub-stations and sub-stations with running machinery per kilowatt installed; also give the total capital costs of the sub-stations.

Distribution line.

38. What system is employed for conveying the current to the electric locomotives or motor-cars? What is the position of the conductors relative to the centre line of the track?

Where a third rail is employed, please state the distance between successive insulators; of what type are these insulators, how are the rails connected at the joints, and what arrangements are made in connection with the expansion of the rails due to heat? Are the wires supported in the fashion employed in tramway practice, or is a catenary suspension used? (State contracting firm.) Are special cables or wires used for suspending the overhead wire, and, if so, which form and which material has given the best results? What kind of insulators are used, and is the insulation to earth single, double, etc.?

Please supply, if possible, a sketch illustrating the design of the overhead line or third rail respectively.

39. What is the number of overhead wires or conductor rails? What is their cross section (in square inches), form (sketch, if possible), conductivity and strength?

40. Are the overhead wires supported by means of wooden poles, iron poles or poles of armoured concrete? In the case of standards of iron or armoured concrete consisting of several parts, state the cross sections of the various parts and the stresses for which they are designed.

What is the height of wire above rail level in the open country and in stations respectively; have these heights proved suitable?

41. What spacing (in yards) has been adopted for the poles on straight lines? What is the distance between poles in the various curves?

42. What provisions are made for the return of the current; what type of rail bonds are used and with what success? Have tests been carried out to measure the rail resistances, the ohmic and inductive drop at normal load and normal working frequency, and, if so, with what results? If not, what values were used as basis for the calculations?

43. Are special means employed for preventing disturbances in the electric arrangements for communication, and, if so, with what results?

What were the disturbances observed in telephone lines with double wire, and in telephone and telegraph lines with single wire and earth return?

Could the disturbances due to induction or influence be removed by suitable measures in the lines themselves, or was it necessary to provide the stator and rotor of the motors with teeth of special form and in particular numbers so as to avoid higher harmonics? Or had other expedients to be employed, and with what results?

44. What is the length of the conductor rails or wires (in miles) in the sidings of the stations? Are the sections of the wires in the stations the same as in the open?

45. What are the capital costs (per mile of railway line) of the conductor rails or wires including the return path?

a) Outside the stations for single and double track respectively;

b) In the stations.

What proportions of this capital cost fall on that portion of the poles which is also used for carrying feeder lines, and on the conductor wire proper, completely erected?

E. — Rolling stock.

46. What form of current is used, and what is the line voltage; in the case of alternating current, please also give the frequency?

47. Are motor-cars or locomotives, or both,

in use, and in what numbers? Are different locomotives used for goods, passenger and express service respectively? How many motorcars and locomotives are kept ready for service emergencies and other exceptional occasions?

The following questions refer both to motorcars and locomotives, and a distinction should be made, where necessary, between locomotives for goods, passenger and express service.

48. What type of motor is employed. What means are employed for obtaining good commutation in single-phase commutator motors and with what results?

Please give as much detail information as possible on the dimensions of the rotor and stator cores, the form and number of slots (see also question No. 43 regarding the disturbing influence on telephone and telegraph lines), length of air gap, commutation poles, windings, resistance connections, number of segments, dimensions of segments and brushes, etc.

49. Please state the output of the motors in horse-power and the pull (in lb.) at the periphery of the driving wheels without artificial cooling, and the corresponding speeds. What is the maximum continuous draw-bar pull of the motorcar or locomotive (in lb.) and at what speed? Is artificial cooling employed, and, if so, by what amount does this increase the motor output?

Please append, if possible, the characteristic curves of the motors, showing brake horsepower, speed, current, voltage, input in watts, efficiency and power factor, with the tractive pull as abscissal.

50. Please state the number of motors per motorcar or locomotive and the weight per driving axle and trailing axle.

51. What is the maximum speed in miles per hour on straight level lines?

52. How is the speed regulated?

(Please describe the speed-regulating arrangements.)

53. What type of controller is employed for starting and controlling the motors? Is the design such that defective parts may be easily replaced?

54. Is the multiple-unit system of control employed to enable the driver at the front end of the train to control the different motorcars or locomotives? Or are arrangements provided to enable the train to be pushed in a satisfactory manner by a second locomotive?

(Please describe these arrangements, and append, if possible, a diagram of connections.

55. What design of transformer is employed? What is their output and weight? Is one transformer sufficient for feeding all the motors?

56. How is the wiring connecting the current collector with the apparatus, transformers, starting and controlling gear and the motors carried out?

57. What kind of current collectors are used and in which way are they put in and out of action from the driver's platform? How many current collectors are in simultaneous use?

58. What design of service brake is employed, and what auxiliary brakes are provided in addition? Of what type are these auxiliary brakes?

59. Are the motors directly mounted on the driving axles, or do they drive them by means of gear wheels or connecting rods? Has the adopted design given satisfaction in all respects, or which drive do you prefer? Have considerations concerning quietness of running and wear and tear of the permanent way influenced your choice of the height of centre of gravity, and therefore the situation of the motors and the driving arrangements? Are bogies or free axles employed, and, if so, of what design? How are the motors fixed in the motorcars or locomotives?

Has special attention been paid to obtain fixing and driving arrangements and easy access

to the motors, particularly in connection with the renewal of worn parts?

Please append, if possible, a drawing giving all essential information regarding the design of the motorcars and locomotives; in the latter case, more particularly, the design of the frame, the fixing arrangements for the motors, the driving gear, lubrication arrangements and other important mechanical and electrical details should be clearly shown.

Please give the names of the firms which have supplied the electrical equipment, the locomotive part and the carriage work respectively.

60. At what intervals, or after what mileage do inspections take place, and how much time do they occupy? What is the maximum life of the gear wheels (in miles)?

61. Is it possible to return energy to the line on down-gradients? If so, is use made of this feature and with what results? What is the amount of the returned energy in per cent of the energy taken from the line?

62. In what manner are the trains heated and lighted; describe the arrangement and design of the apparatus installed for these purposes.

63. What arrangements are provided for giving signals?

64. Please give the weight of the complete motorcar or locomotive, and also the weights of the different parts of the electric equipment, *viz.* motors, transformers, switch gear, wiring and current collector. What is the weight of one motor, and the weight per horse-power?

65. How many passengers does a motor-car hold?

66. What is the capital cost of a motorcar or locomotive ready for service? In the case of locomotives, please discriminate between the various types.

F. — Service organisation and results.

67. What is the maximum number of passenger trains, goods trains and mixed trains per diem? How large is the traffic on the railway, expressed in train-miles and ton-miles, on an aggregate and for the various classes of trains in the various months and during a whole year? Please append, if possible, a diagrammatic time table, showing the times taken by the various classes of trains, the head way between trains and the daily hours of service.

68. What is the acceleration at starting for the different classes of trains?

69. What is the weight of the longest trains propelled by motor-cars?

Please state the weights of the trains drawn by locomotives (excluding the weight of the locomotives themselves) for the various classes.

70. What is the maximum load (in kilowatts) on the power station for days of maximum and minimum traffic? Please also give the average load (in kilowatts) per day of twenty-four hours for the days of maximum and minimum traffic. How many kilowatt-hours are supplied by the power station to the railway distribution network per annum?

Please supply, if possible, a set of curves showing the output generated in the power house during days of maximum and minimum demand from the railway and over a whole year.

71. Where the railway has its own power station, please reply to the following questions :

a) Is current supplied from the power station for lighting and power in connection with the railway, and, if so, what is the capacity of the connections in kilowatts and how many kilowatt-hours are supplied per annum for these purposes?

b) Is current for lighting and power supplied to private consumers, and, if so, what is the capacity of the connections in kilowatts, and how many kilowatt-hours are supplied per annum?

What is the area of this supply, and at what prices is the current sold?

Would the railway load (including the supply for auxiliary railway purposes) be sufficient to cover the running costs of a suitably large power station, or is it necessary to rely on outside consumers?

72. What is the cost per kilowatt-hour generated in your own power station when :

a) Measured at the power station?

b) What are the additional costs for the feeder lines, including the transformers at the feeding points?

c) What are the additional costs for the overhead equipment of the line?

In items *b*) and *c*) please give the total additional cost, and also the additional cost per kilowatt hour supplied by the power station to the feeders.

If possible, please give detailed tables of working costs separately for the power station, feeder lines and overhead equipment, showing the various items of expenditure, such as wages and salaries, fuel and other material, and further, the maintenance and renewal costs, interest and amortisation, the last four items to be given in per cent of the capital cost. What is the cost of the fuel (per ton) delivered at the power station?

What is the yearly average amount of fuel (in pounds) burned per kilowatt-hour supplied by the power station, including all losses due to starting up the boilers and running the condenser plant?

73. How much do you pay per kilowatt-hour if brought from an outside source? How many kilowatt-hours do you buy per annum?

Please state where the energy is measured.)

74. What are the total maintenance costs, interest on, and amortisation of the capital cost for the electric rolling stock and its various parts?

75. What is the consumption (in watt-hours) per gross ton-mile, as measured.

a) at the power station?

b) at the current collector?

76. What are the working costs per gross ton-mile?

In this connection the following items should be taken into consideration :

1° The cost of the energy consumed, calculated for the power station;

2° The total costs of the feeders and transformers;

3° The total cost of the overhead equipment;

4° The maintenance cost of the electrically-equipped rolling stock;

5° Wages bill of the train staff (locomotive staff);

6° Cost of materials for the service.

What would be the corresponding working cost for steam traction?

What would have to be the cost of a kilowatt-hour (measured at the feeding points) if electric traction is to be at least as cheap as steam traction?

77. Are the drivers of the motorcars and locomotives technically-trained men? Of how many men is the staff of the motorcar or locomotive composed? Have you taken advantage of the easy manipulation of electric motorcars and locomotives by including in the train staff an employee trained in the working of the motor equipment, so as to prevent the service being dependent on one man?

78. Have any important interruptions or dislocations taken place on the electric railway, and, if so, what were the causes? Have electric motorcars or locomotives possessing a low centre of gravity (and producing therefore greater side pressures, more especially in curves), given rise to greater stresses in, and greater wear and tear of, the rails than steam locomotives? If so, in which way has this shown itself, and what mea-

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sures were taken to prevent or reduce the trouble?

79. Do steam-driven trains run over the line in addition to the electrically-operated ones? If so, in what numbers and for what reasons? Are shunting operations done exclusively with electric motorcars or locomotives?

80. Has the railway been worked electrically from the very commencement? Or has steam operation been replaced by electric traction, and, if so, for what reasons, and what advantages have been secured? Since when has the electric installation been definitely in operation?

81. Has it been found that the operation of the power station, which supplies low-frequency current for the railway, has been appreciably complicated by supplying current at a higher frequency for power and lighting to private consumers? Have special generating sets for higher frequency (50 cycles per second) been installed for this purpose in the power station, so that the private supply is quite independent from the railway supply?

Or is current taken at certain points of the railway distribution network and converted to current of higher frequency by converters?

[621 .33]

REPORT N° 4

(all countries except Germany, America, Austria and Hungary)

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MANAGER OF THE ELECTRICITY WORKS OF THE CANTON OF ZURICH,
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(*Translation.*)

FIRST PART.

I. — Introduction.

It would have been the duty of the reporter, who was requested by the Swiss Federal Railway to prepare this report, to give particulars about the state of this question of electric traction, in Switzerland and the other countries, excluding America, Germany, Austria and Hungary. Unfortunately shortly after he had undertaken this work, he was appointed to a new and very responsible and exacting post, which deprived him of the leisure necessary for attending to the subject soon enough and thoroughly enough; moreover, the information sent from other countries was not sufficiently complete to enable him to present a complete view of the state of electric traction in other countries. The general secretary of the Congress (by agreement with the author, who intended in this way to maintain a certain uniformity of treatment) had sent the railway administrations concerned a list of questions worded in the same way as those drawn up by the esteemed author of the German report, Professor Gleichmann, for his country. However, only a few answers containing definite information were received from other countries.

As regards *Switzerland*, more complete information concerning electric railways

was at our disposal, but naturally, considering the small size of our country, it did not concern large schemes. For the past ten years, our country has been a comparatively active experimental field for the development of electric traction not only on city tramways, but also on main railroads and on special and branch railways, of which some, such as the Burgdorf-Thun Railway, the first three-phase standard-gauge railway, although only of modest mileage, have marked an important step in advance in the question. Since then we, like everyone else, have been working on the difficult problems of adapting electric traction serviceably and also economically to standard-gauge railroads, carrying heavy loads, and covering considerable distances. This required extensive work, in which, during the past decade, our well-known, capable and energetic Swiss manufacturers have helped considerably and at no little sacrifice. Thanks to their activity we can, today, particularly refer, among other things, to the practical working of the single-phase system with high-tension contact line, as shown by the four years' experimental operation at Seebach-Wettingen, conducted by the Oerlikon Works; also to the practical success of the three-phase system of Brown, Boveri & Co., for heavy traction through long tunnels, at the Simplon; these are important examples, among the few existing ones, of electric traction on main lines. The electrification of main-line systems is so important a question, particularly from the financial point of view, that even if the technical success appears certain, the economical side and consequently the question of most favourable solution must be very thoroughly investigated before one can think of electrification or even of making more extensive trials on important sections of a main-line system. Besides actually operating electric traction, of different systems, on railways with heavy and with light traffic, we in Switzerland have advanced in the *comparative study* of these systems. It was apparent, seeing how divergent opinions still were from a purely technical point of view, that it was advisable to collect and examine the theoretical material, as well as that derived from practical experience. The Swiss Federal Railway as well as the Federal authorities strongly supported the appointment of a *Swiss commission for investigating electric traction*; this proposal was due to the initiative of technical societies and manufacturers. Since 1904, this Commission of investigation has, with the help of technical assistants and professional commissions, dealt with all questions affecting electric traction on our railways.

The investigations were carried out with the assistance of railway experts, especially those of our Swiss Federal Railway, and with that of the Swiss manufacturers who represented all the systems in question. They included *inter alia* the drawing up of comprehensive time-tables of various kinds (present and possible future), the calculation of the power required at the generating station and that utilized on the track, the technical comparison between all details of the different systems both theoretically and from the point of view of practical experience, economical comparisons of the various systems, and finally, the drawing up of complete plans and power schemes, for the electrical operation of some typical systems (St. Gothard

Railway and Federal Railway District II); including, as far as possible, particulars of the cost of the water-power installations. In the first place, an investigation of the water-powers available was made. Quite recently the working projects were in part revised on the basis of more suitable running schedules.

The possibility of a satisfactory electrification of the entire Swiss railway system depends upon the results of this examination of the water-powers, principally because their distribution is unequal; these results are hardly suitable for publication, and they also are not yet quite complete.

On the other hand, the investigations concerning the questions of system and cost give a very good conception of the state of these questions in Switzerland, and the author believes, therefore, that he can best elucidate subject VIII for the Congress as regards the above points in Switzerland, by reproducing the results of the studies of the Commission and adding some supplementary information. This is done by agreement with the Swiss Commission of investigation and the Swiss Federal Railway. We believe we may therefore assume that the report will not be prejudiced, if these statements are also published in the same form in the reports which the Swiss Commission is going to publish about its work.

A large portion of the detailed studies of which we here give the results, is the work of our colleague L. Thormann (engineer, Berne); another is due to Dr. W. Kummer (engineer, Zurich) and to Mr. Weber-Sahli (Biel). The Oerlikon Works, Messrs. Brown, Boveri & Co., and the Alioth Electric Company have collaborated in carrying out special investigations concerning questions of construction and the determination of the cost of manufacture of individual details.

In what follows, we begin with a statement showing the present state of the questions of system and of cost in Switzerland, as deduced from these investigations; in a second portion, we give a description of the principal more recent Swiss electric locomotives for standard-gauge railways, and of the locomotives constructed by Swiss manufacturers generally; while in a third portion we give, in a tabular form, the information about electric traction received from Switzerland and other countries, combined with that concerning the Swiss electric railways, as time unfortunately does not make a more comprehensive study of the foreign information possible.

In order to be able to compile this report, in spite of the obstacles which had cropped up, the writer, in agreement with those who commissioned him, availed himself of the assistance of Dr. W. Kummer, engineer, of Zurich; the author takes this opportunity to thank him heartily for his co-operation.

II. — The question of system.

At the outset of their labours, the Swiss Commission of investigation was faced by the question: Are any electric-traction systems in existence, which really sufficiently satisfy all the requirements of a main railroad? Today, the engineer can definitely answer yes to this question; we can be sure of the success of electric traction.

In addition, the question (taking first of

all a purely technical standpoint) as to which system, in particular cases, and which in general, give the greatest advantages, has, as we all know, been solved to a large extent in the past few years. In Switzerland in particular, this question is it is true more difficult to answer, as the conditions are very diversified and the most important point here is the economical advantage of water-power operation. In what follows, we shall describe the course of those investigations and the conclusions of our Swiss Commission, relating to this question. In this connection, we will again repeat that all determinations of the relative advantages of the different systems, and the assumptions as to what can really be done without risk of failure have been considered jointly by the manfacturers and representatives of the different systems, together with the members and other experts of the Commission.

We began by investigating the purely technical adequateness of the different systems; firstly, from the standpoint of the requirement which a traction system for a railway must satisfy, and then from that of the relative electro-mechanical and economical advantages of the system; the conclusion of the investigations will give us, in the first instance, the comparisons of cost based on detailed projects, which will be considered in the next chapter.

The comparison of different systems makes it necessary to take definite figures for the voltage and other technical conditions proposed, based upon previous experience, and taking the safety of the service into consideration.

We therefore give a list of proposed systems, in which the supply of current to the trains is effected by a contact line and rail return, as follows :

Direct current with third rail for voltages up to 800 volts;

Direct current with overhead wire for voltages up to 3,000 volts

and eventually $2 \times 3{,}000$ volts with three-wire distribution; as a rule, in both cases substations are provided to which the energy is transmitted in the form of high-voltage current by an overhead line;

Three-phase alternating current with two overhead wires supplied at from 5,000 to 8,000 volts, and periodicities of from 15 to 50 per second, with a main supply at higher voltage stepped down at transformer substations, which if necessary may also act as balancing stations ;

Single-phase alternating current with overhead wire up to 15,000 volts, and from 15 to 25 periods per second, whether generated as single-phase current or derived from three-phase current of higher voltage transformed at substations, which can also be used as balancing stations.

The limit of permissible voltage is in the first place governed by the train-equipment, and specially by that of the motors driving the axles. For direct-current motors 500 volts and even 800 volts have for some considerable time proved satisfactory. For motors of greater power, as well as for those of higher voltage in which the armature windings can still be bar wound, we find higher voltage used successfully with two commutators per motor (St. Georges de Commiers-La Mure 1,200 volts; Vienna Stadtbahn 1,500 volts per motor); recently we noted the use of 1,000 and 1,200 volts per commutator by the addition of auxiliary poles, and latterly

especially on American interurban lines. For the immediate future, one can therefore well count on 1,500 volts per commutator.

For all single-phase and multiphase systems, which are supplemented by train transformers, the limitation of the voltage at the motor need no longer be considered in determining the voltage of the contact line. Without train transformers, three-phase induction motors supplied at 3,000 volts in service (Valtelina, Simplon) and also 10,000 volts experimentally (Berlin, Zossen), have been successfully used; for large motors, 5,000 volts can be considered practicable; with single-phase commutator motors, worked on the induction principle (Winter-Eichberg, Déri, etc.), 6,000 volts are indeed used and certainly admissible; for those working on the pure series-principle, even in the case of large motors, not more than 300 or 400 or at most 500 volts can be considered, in which case the train transformer is necessary.

The supply in volt-amperes required for the given conditions of acceleration and running also influences the choice of the voltage; their absolute magnitudes are most favourable with direct-current motors; but as three-phase and single-phase systems are used with considerably higher voltages, no influence on the figures quoted results.

The effect of variations in voltage on the working of the motors influences in principle not only the permissible variations in the voltage, but also the choice of the working voltage; this fact should primarily lead to the choice of relatively low permissible voltage variations and higher voltages with three-phase induction motors than with direct-current and single-phase series motors, because with three-phase motors (and only with these) the maximum torque, in case of heavy overload, varies as the square of the voltage.

The driving and controlling gear for the motors has also to be considered in connexion with the permissible voltage. Experience shows, however, that with the use of relay control systems, the control apparatus can, for the same voltage, be made at least as reliable as the motors themselves, even in the case of the high voltages used for three-phase induction motors.

Main switches and contrivances for taking current from the live contact line have already proved satisfactory in practice, in the case of the contact-line voltages assumed above.

There remain the limitations of voltage imposed by the position of the live line. As regards the third rail, to use a higher voltage than that hitherto used (about 500 to 800 volts) is out of the question, owing to the proximity of the track, the difficulties of the mechanical construction required, the impossibility of obtaining proper insulation, and the danger to persons.

With a single-wire overhead line, as used for single-phase current, 15,000 volts have proved successful in the open country (four years' working on the Seebach-Wettingen line), and experiments (Swedish State Railway, etc.) have been successfully made with higher voltages. It is true that as regards wet tunnels, trials and results are still lacking; more recent experience (Simplon) seems to indicate that it is probably advisable to limit the voltage to about 10,000 volts.

With the double-wire overhead system for three-phase current (and with the

direct-current three-wire system, if that is used), 3,000 volts have been successful (Italian lines, Simplon, latterly 6,000 volts on the Great Northern Railway), and 6,000 volts can certainly be counted upon; we adopted the opinion of the builders of such lines; according to their experience one can without hesitation go to 8,000 volts.

We consequently give the following as the permissible limits of voltage for electric traction :

—	For direct current.	For three-phase current.	For single-phase current.
With reference to the motors.	1,500 volts per collector. 3,000 volts per motor.	5,000 to 8,000 volts.	400 to 500 volts for the series motors. 6,000 volts for commutator motors on the induction principle.
With reference to the contact line	800 volts in the third rail. 3,000 volts for the single-wire overhead line. 2×3,000 volts for the two-wire overhead line.	5,000 to 8,000 volts for the three-wire overhead line.	15,000 volts for the single-wire overhead line.

These considerations have led to the above-mentioned determinations concerning the three comparable and available systems. The reasons for the periodicities provisionally assumed depend on the motors and on the distributing arrangements; the later reduction of periodicity in the case of single-phase current will be the subject of special discussion.

The operation of a railway makes the following chief demands on traction systems :

1° The production of the torques and horse-power necessary for operating standard-gauge railways;

2° The maintenance of the schedule under all possible traffic conditions, taking the existing characteristics of the motors (particularly as regards the running speed, its maximum, its control and the relation of speed to tractive effort) into consideration;

3° The production of sufficient initial acceleration, in particular;

4° The possibility of traction by multiple units.

Only a few years ago, it was doubted whether any possible traction system could give sufficient power for standard-gauge railway operation. With rail-motor cars, in the case of passenger trains, this was soon proved practicable with all systems; the subdivision of power over several rail motor cars led to the use of small motor units; and their construction made such rapid progress that despite the small space available, they developed the power required. As regards the direct-current system, this was already proved when our work began, mainly by the New York Subway (1) and other urban and interurban railways; in our own country we can refer to the Montreux-Bernese-Oberland and the Freiburg-Murten-Ins rail-

(1) See for example *Elektrotechnische Zeitschrift*, 1905, pp. 111 et seq.

ways, which, however, are only of small power. Our three-phase lines of the Burgdorf-Thun Railway and the Engelberg Railway are also not very important, but they permitted us at an early stage to recognize the possibility of heavier three-phase rail-motor-car operation. As regards single-phase traction with commutator motors, we can now also refer to existing lines; for instance, there is the Hamburg-Altona line with a great number of rail-motor cars operating an important traffic; in addition, in our own country there are the Locarno-Maggiatal Railway, the Seetal Railway and the Martigny-Orsières Railway, which, however, operate smaller traffics. The question of locomotive traction remained more doubtful for a long period; here more powerful motor units are required and always will be required for express trains and goods trains: in our country especially for hauling the foreign express steam trains arriving at our frontier. Today, we record that it has now been proved in practice that all the systems under consideration give a sufficient power capacity, even in the case of locomotives. The direct-current equipment of the Baltimore and Ohio Railroad, now in use for years, consists of locomotives supplied by the General Electric Company (1895 type), which have an hour rating of 1,440 horse power at full voltage, each of the four motors being capable of developing 360 horse-power; it is true they required improvements which were successfully introduced. The locomotives of the New York Central (also built by the General Electric Company) have now also been in use for a considerable time; they have an hour rating of 2,200 horse-power, and an output of 550 horse-power per motor, and haul double trains weighing 889 tons at a speed of 75 kilometres (46·6 miles) per hour. In addition, we may also mention the experimental locomotive (10002) built by the Westinghouse Co. for the Pennsylvania Railroad, with motors giving a continuous output of 350 horse-power each. All these examples refer to slow-speed direct-current motors mounted direct on the driving axles. Since then, further advances have been made in the direct-current system, in the slow-running motors with fixed casings, driving the axles by means of connecting rods, with a twenty minute rating of 2,000 horse-power, as built by the Westinghouse Co. for the Pennsylvania Railroad and capable of developing 4,000 horse-power per double locomotive (1). In the case of three-phase induction motors, we have the practical proof in Switzerland at the Simplon, where the new Brown locomotives of 1907, each with two 850 horse-power motors with fixed casings, connected with the driving axles by an arrangement of parallel cranks and connecting rods, have an hour rating of 1,700 horse-power, and attain 75 kilometres (46·6 miles) per hour when hauling trains of 300 tons, and 35 kilometres (21·7 miles) per hour when hauling trains of 400 tons uphill (original report in *Zeitschrift des Vereins deutscher Ingenieure*, 1909, p. 607; see also our description). Doubts were at first entertained as to the possibility of constructing single-phase commutator motors sufficiently large for operating trains, but all such uncertainty has now ceased; one remembers the four years'

(1) *Electrical World*, 4 November 1909.

trial made hy the Oerlikon Works, at Seebach-Wettingen, where, on account of the small space, locomotives with an hour rating of only 500 horse-power could be employed, having two motors, each of 250 horse-power carried on the side frames and driving the axles by means of gear wheels and coupling rods (1); also in particular the New York & New Haven Railway, which used locomotives with an hour rating of 1,000 horse-power with four motors carried direct on the driving axles, hauling express trains of 250 tons at 115 kilometres (71·5 miles) per hour, and locomotives with an hour rating of 1,200 horse-power with four motors hauling goods trains of 1,350 tons at 56 kilometres (34·8 miles) per hour and passenger trains of 720 tons at 72 kilometres (44·7 miles) per hour (2). Further we can mention the contemplated scheme of the Midi Railway (France), which is having several locomotives of different designs constructed by different makers, among whom we may mention the Swiss firms Brown, Boveri & Co., and the Winterthur locomotive works; also a locomotive from the "Allgemeine Elektrizitäts Gesellschaft", with two motors, each with an hour rating of 800 horse-power, and finally also the provision now being made on the Dessau-Bitterfeld line for working with locomotives of different power, made by different makers; the two last examples have been described (3). Consequently our Berner Alpenbahn Company has also adopted large single-phase locomotives for operating the Lötschberg traffic; these are in course of construction and their powers will be as follows: the locomotive of the Oerlikon Works, an hour rating of 2,000 horse-power in two motors, and the locomotive of the "Allgemeine Elektrizitäts Gesellschaft" of 1,600 horse-power in two motors (1).

The conclusion of our Commission of investigation, that all these systems can give sufficient power, either by automotors or by locomotives, is now fully confirmed.

The horse-power a motor can develop is not of itself a proof that it will suffice for a given tractive purpose; above all it must develop the necessary tractive effort; therefore the motors must be capable of utilizing the entire adhesion for tractive purposes. If we assume a coefficient of adhesion of 0·2 and a load of 15 tons on the driving axles (a fair assumption with us), then a driving axle can, at most, develop a tractive effort of 3,000 kilograms (6,614 lb.), which accordingly must be considered the maximum which the motors must supply per driving axle. In order to compare this with the horse-power output, the existing speed and the peculiarities of the line must be taken into account. Of this maximum tractive effort, the fraction necessary for the acceleration must be reserved for starting, in accordance with our former assumptions; consequently at most $^2/_3$ to $^3/_4$ of this tractive effort, say 2,000 to 2,250 kilograms (4,400 to 4,920 lb.), remain for the actual running.

(1) See for example, Report in the *Schweizerische Bauzeitung*, vol. LI, 1908, pp. 185 et seq., and vol. LIV, 1909, pp. 54 et seq., as well as our description.

(2) See *Elektrische Kraftbetriebe und Bahnen*, 1908, p. 81, and 1909, p. 573.

(3) *Revue générale des chemins de fer*, 1910, and *Zeitschrift des Vereins deutscher Ingenieure*, 1910.

(1) *Schweizerische Bauzeitung*, 1910, vol. LV, p. 202, see also our descriptions.

Based on these figures for the tractive effort, we therefore have the following :

For a speed, in kilometres per hour, of :	Motor output per driving axle, in horse-power.	Maximum allowable weight, in kilograms, per horse-power.
90	666-750	22·5-20
75	550-625	27-24
60	444-500	34-30
50	370-416	40-36
40	298-333	50-45

For every speed, and in fact for every traffic requirement, the weight admissible per unit of output accordingly varies.

Table A, which gives a number of existing locomotives, shows that the locomotive weights above given have been exceeded in the majority of cases by the electric locomotives at present in use. Conditions will however probably be very rare under which it will be necessary to utilize, when running at full speed, between $^2/_3$ and $^3/_4$ of the tractive effort made possible by the coefficient of adhesion; generally, a larger amount will be reserved for the initial acceleration, so that probably only $^1/_2$ of the maximum tractive effort will have to be used when running at full speed, and the actual weights can then be 50 per cent greater than those given in the above table, or even more. Table A accordingly shows that some of the more recent electric locomotives satisfy these reduced requirements; that is to say, they can accomplish all their adhesion will permit. On the other hand, even the most recent steam locomotives are far from satisfying the requirements.

As regards the possibility of keeping to the running schedule under all possible existing conditions, the different systems are not equally satisfactory.

Viewed from this standpoint, the operation of railways requires : *a*) variation of speed within wide limits for every conceivable tractive effort; *b*) maintenance of schedule time within the limits of the train weights, irrespective of the actual weight of the train and the amount of traffic on the section; *c*) the ability to maintain the maximum allowable (legally permitted) speeds even on up gradients, in so far as this is not limited by the economical conditions of the whole system (particularly in the case of water-power); *d*) to make up time when the train is late, under exceptional conditions, by running at full speed on up gradients where, in accordance with the last remark made under heading *c*, this is otherwise not the usual practise.

Starting with the nominal output of the motors expressed in horse-power and the corresponding normal torques, the latter may be said to be (with all classes of motors) proportional to the active motor dimensions, the induction in the air-gap, and the armature ampere-turns. With single-phase, as well as with direct-current commutator motors, every speed necessary in practice can be obtained with this torque, by suitably selecting the voltage applied; with three-phase induction motors, this would only be possible by a simultaneous regulation of the periodicity, proportionately to the voltage. One must therefore, in the present state of knowledge, have recourse neither to transformer locomotives for simultaneous voltage and periodicity control; nor to the use of auxiliary generators

on the train, to obtain variable armature voltage by independent excitation of direct-current motors; nor to the use of boosters to obtain higher voltages, either positive or negative; nor to that of several other regulating appliances, as all these are too complicated for practical use. If, therefore, we use only relatively simple regulating methods in order to accomplish the above-mentioned (under *a*) requirement of obtaining different speeds with one and the same tractive effort, then the following means are possible :

In the case of direct-current motors, we can use two or four motors coupled in series parallel in order to obtain graduated speed differences; in the case of three-phase current with a single motor, we can use the commutation of poles for the same purpose, and with two or more motors we can couple them in cascade. (Consideration and experience show the superiority of the first system over the second; also with the first the different steps are not so nearly of equal magnitude as with the series-parallel coupling of direct-current motors; but this is of minor importance.)

With direct-current and three-phase motors the use of rheostats is a simple but uneconomical manner of obtaining the graduations of speeds between the different fundamental speeds.

With the single-phase commutator motor with series characteristics, the desired change of motor voltage and speed can be effected by means of voltage transformers for the contact line voltage in question; these, while increasing the weight of the rolling stock, are nevertheless necessary.

The following table gives particulars of the results obtained with the regulation referred to, based on the published curves of tractive effort and speed for the actual motors used.

With direct-current motors, series-parallel and rheostatic regulating of various patterns are used by the Alioth Co. (for example on the Bernina Railway); with three-phase induction motors the commutation of poles (changing of pole connections) is used on the most recent Simplon locomotives of Brown, Boveri & Co., and in the single-phase motors of the Oerlikon locomotives of the Lötschberg Railway the secondary voltage is regulated.

Attainable speed variations with different current systems.

TYPE OF MOTOR.	Speed steps, in kilometres per hour.	Normal tractive effort Z_0 at wheel periphery, in kilograms.	Normal fluctuations of tractive effort, necessary to operate trains, in percentage of Z_0.	Method of regulating the speed.
Direct-current series motor, Alioth G. T. M. 65; normal speed = 45 kilometres per hour.	11·3 16·9 22·5 33·7 *45·0* 56·3	400	0-125	Series-parallel coupling and shunt control for points wich do not lie on the characteristic curves.
Three-phase induction motor of the 1907 Brown Simplon locomotive.	26 35 53 70	5,750 5,000 3,850 3,200	0-125	Pole-changing control.
Single-phase series motor of Oerlikon Lötschenberg locomotive; normal speed = 42 kilometres per hour.	10·5 16 21 32 *42* 52·5 70·0	6,400	0-125	These and other intermediate speeds are obtained by regulating the voltage by means of transformers.

The keeping up of schedule time (point *b*) is thus economically obtained with direct-current motors in rich control by series-parallel and with three-phase motors on high-powered locomotives in which control by commutation of poles (changing of pole connections) can be used; and a sufficient number of possible speed variations is thus obtainable economically. With smaller powers (rail motor cars), this is, on the contrary, only possible by the use of uneconomical rheostatic control, and it is also necessary that in every instance, even when the load on the section is a maximum, the drop in voltage shall not be too great. The single-phase commutator motor, on the other hand, satisfies requirement *b*) economically, and makes it possible to meet, with the help of voltage regulating transformers, even an exceptional voltage drop on the line; this motor can, therefore, satisfy condition *c*) which the three-phase induction motor can do of itself, and which the direct-current motor cannot fully satisfy.

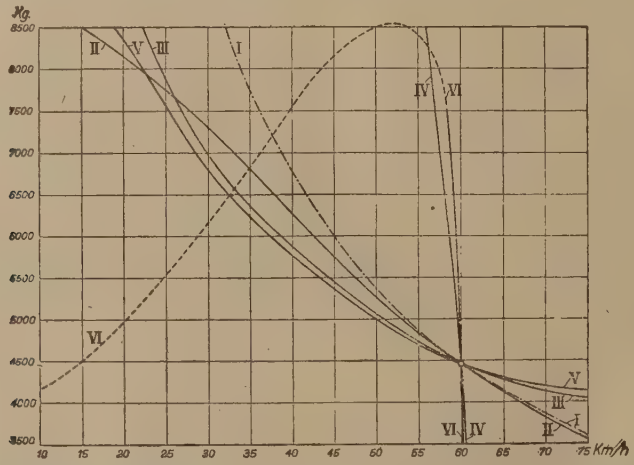
The exceptional increase of speed as per *d*) is partly possible in the direct-current motor by weakening the field by means of a shunt, but it is restricted by the consequent lowering of the voltage in the contact wire; with the three-phase induction motor, it is only possible if there is a reserve speed step not ordinarily used, or used only on gradients; with single-phase commutator motors, a suitable arrangement of the regulating transformers makes this possible.

The railway engineer attaches great importance to the question of making up lost time. Irrespective of the barely possible shortening of the regular stops, it can be accomplished only by generally increasing the speed on the gradients; in other words, by using to the greatest possible extent the maximum speed allowable over the entire section. This, however, can only be accomplished if the motors satisfy requirements *c* and *d*.

The performance of motors not pro-

vided with means for regulation does not really come under consideration for traction, although it indicates the natural adaptability of the peculiarities of the motor to the requirements of railway operation, and is of importance in the case of those motors in which the attainment of intermediate speeds is generally possible only through the use of uneconomical regulating appliances (three-phase induction and direct current motors); it is, moreover, particularly interesting in comparison with the performance of the steam locomotives hitherto used. From this point of view, we would refer our reader to the following curves showing the performances of different types of motors, all with the same normal tractive effort and capable of developing the same power for one hour. A curve for a "constant-power motor" is also added, as the ideal, from the electrical standpoint, for the motor itself, and it also would be desirable in order to obtain a more uniform load on the power station when water-power is used.

Our conclusion is that the conditions necessary for the maintenance of the schedule are completely satisfied by single-phase commutator motors, while only partly so by direct-current and three-phase induction motors, although these may also meet the requirements of practice in most cases.



Tractive effort speed curves of different railway motors without regulation for a nominal output of about 1,000 horse-power at a normal speed of 60 kilometres (37·3 miles) per hour.

I = Theoretical curve for the same output (1,000 horse-power);
II = Steam engine of B 3/4 superheated-steam locomotive of the Swiss Federal Railway (see *Schweizerische Bauzeitung*, vol. LV, p. 105).
III = Direct-current series motor;
IV = Direct-current shunt motor;
V = Single-phase series motor, or repulsion motor.
VI = Three-phase induction motor.

In order to compare the various motor systems under review with reference to the starting conditions, it is necessary to determine the relation of the necessary trac-

tive effort at starting to the normal tractive effort corresponding to the normal or hour rating. With this object in view, we must first of all determine under what conditions (gradients and train weights) the motors must develop their normal or so-called hour rating. The latter determination will vary greatly with different railway profiles, and this circumstance has a very great influence on these conditions, particularly in the case of our mountainous country. Consequently, that acceleration (considered as a mean, and as uniform) must be fixed, which is deemed necessary for traction on the various gradients. We will assume that with electric traction on Swiss railways a mean acceleration should be attained of 0·3 metre (0·984 foot) per second per second with passenger trains, of 0·2 metre (0·656 foot) per second per second with express trains, and of 0·1 metre (0·328 foot) per second per second with goods trains. These accelerations are, on the whole, greater than those which existing measurements show are obtained with the present steam service, as, according to these, the accelerations hitherto obtained never exceeded 0·15 metre (0·492 foot) per second per second with slow and express passenger trains, and 0·1 metre (0·328 foot) per second per second with goods trains.

Assuming a mean rolling resistance of 5 kilograms per ton (11·2 lb. per English ton) we obtain, when the normal power and normal pull Z_0 are fixed :

—	On gradients of										
	10 °/₀₀			15 °/₀₀				20 °/₀₀			
For starting on gradients of	0 °/₀₀	5 °/₀₀	10 °/₀₀	0 °/₀₀	5 °/₀₀	10 °/₀₀	15 °/₀₀	0 °/₀₀	5 °/₀₀	10 °/₀₀	20 °/₀₀
the following accelerations in metres per second per second are obtained :											
with an initial tractive effort of :											
$Z = 2\,Z_0$	0·25	0·20	0·15	0·35	0·30	0·25	0·20	0·45	0·40	0·35	0·25
$Z = 3\,Z_0$	0·40	0·33	0·30	0·55	0·50	0·45	0·40	0·70	0·65	0·60	0·50
and the following initial tractive efforts, expressed as multiples of the normal tractive effort Z_0 :											
for an initial acceleration of											
$a = 0·2$ metre per second per second.	1·66	2·00	2·3	1·25	1·5	1·75	2·0	1·0	1·2	1·4	1·8
$a = 0·3$ — — —	2·3	2·6	3·0	1·75	2·0	2·25	2·5	1·4	1·6	1·8	2·2

For the Swiss railways, the normal tractive effort of the motors will almost always have to allow for gradients of from 10 to 20 per mil. For this case, the table shows that the necessary starting accelerations are always attained and mostly considerably exceeded, when the starting pull is double the normal pull. This can, however, now be attained without difficulty with all three motor systems.

With direct-current motors, about 1·7 times the normal current will be required to obtain the double pull, while twice the normal current will produce approximately 2·4 times the pull. With regard to heating, as well as with reference to sparking at the commutator, the consequent increase of current is permissible,

but it cannot be greatly exceeded without damage. With three-phase induction motors with only one speed step, the the maximum torque, varying as the square of the applied voltage, will be, at normal voltage, 3·5 to 4 times the normal, and 4 to 4·5 times the normal current will be used; for double tractive effort, approximately double normal current should be allowed for in this case also, but is only permissible for the short period occupied in starting. With three-phase motors with several speed steps, the maximum possible tractive efforts on the low-speed steps are reduced because of stray magnetic fields, but with sufficient current, it is still possible to obtain double starting torque. With the single-phase commutator motor, the conditions are similar to the direct-current series motors, although more onerous in that the voltage between the commutator segments, creating sparking, cannot be compensated when the motor is at rest, and that only by the choice of low periodicity is it possible easily to obtain the approximately-double normal current necessary for giving the double starting torque.

As examples of the attainable starting torques, and the consequent actual power absorbed and power factors, the following may be submitted.

Attainable initial tractive efforts and corresponding power absorbed by motors of different systems.

—	Tractive efforts, in percentages of normal :					
	50	100	150	200	250	300
Direct-current rail motor, Alioth G. T. M. 65; 750 volts, hour rating 65 horse-power.						
Power absorbed, in kilowatts :						
motor only	2·4	4·7	7·0	9·4	11·7	14·0
motor with starting resistance supplied at constant normal voltage	10·0	14·8	16·1	18·6	22·0	24·0
Three-phase locomotive motor Brown, Boveri & Co, D 16/6-500-320; hour rating 650 horse-power, 16 periods, 3,000 volts.						
Power absorbed, in kilowatts	163	325	486	650	815	980
— — in kilovolt-amperes	248	495	742	990	1,230	1,490
Power factor	0·655	0·655	0·655	0·655	0·655	0·655
Single-phase commutator motor, Déri system, by Brown, Boveri Co.; hour rating 345 horse-power, 25 periods, 1,000 volts.						
Power absorbed, in kilowatts	74	130	168	205	240	264
— — in kilovolt-amperes	222	390	510	620	725	800
Power factor	0·33	0·33	0·33	0·33	0·33	0·33
Single-phase series commutator motor, Oerlikon works, 12 WB; hour rating 1,000 horse power, 15 periods, 500 volts.						
Power absorbed, in kilowatts	20·5	60	97·5	140	190	250
— — in kilovolt-amperes	138	280	420	560	700	860
Power factor	0·15	0·19	0·23	0·25	0·17	0·29

Even the abiliby to develop double normal torque for starting does not fulfil all the desirable attributes for proper starting with the motors. When it is required that the power for starting should not reach too high a value, and thereby (especially with water-power) overload the current supply, the acceleration will not be obtained with constant torque; on the contrary, during the second step, the torque and the acceleration will be gradually diminished so as not to exceed the given maximum value for the starting power. The gradual reduction of the speed, however, satisfies the conditions of actual running already specified.

With the direct-current motor, in addition to series-parallel grouping, there is available only the uneconomical use of rheostatic control at the commencement of the period of acceleration; with the three-phase induction motors, the same can be used, or the stator voltage regulated, in addition to the use of cascade coupling or of commutation of poles (changing of pole connections); with the single-phase commutator motor, economical regulation can be effected by means of a regulating transformer, or by changing the position of the brushes. On the other hand, single-phase motors have very low power factors at starting, or else the current must be relatively large.

On the whole we find that the volt-ampere input for all three types of motors, when giving the assumed necessary double normal torque at starting, is about the same, while the watt input on the other hand is least with the single-phase motor.

The drop of voltage on the contact line, which occurs so readily at starting (especially when several train start simultaneously), is of no practical consequence with direct current and single-phase motors, as only a small portion of the voltage is necessary for the starting, while with three-phase current the attainment of a sufficient starting torque is largely dependent on the voltage drop in the supply not being too large.

The possibility of multiple-unit traction. — In order to operate a proper service, multiple-unit working is necessary, particularly in our country where conditions vary so much; and this is necessary both when rail motor cars and when locomotives are used. The arrangement of a common control for several motors from one central point, even when the motors are on different vehicles, no longer presents any difficulties; the relay multiple-unit control has proved satisfactory and can be adopted for all systems. But the proper co-ordinated working of the motors themselves is also necessary. With series motors, both in the case of direct current as well as in that of single-phase current, the group working of several motors on different driving axles, as well as on different vehicles, presents no difficulty. It suffices to adjust the motors to approximately the same speed, when, in consequence of their series characteristics, the loads will be divided according to the capacities of the motors, even if these are unequal. The practical example of the Montreux-Bernese-Oberland Railway shows that it is not even necessary to have a central control for controlling several rail motor cars, but that separate rail motor cars independently controlled, can be made to work together quite well. As regards multiple-unit

working, there are numerous examples of success with direct current on urban and on elevated railways, especially in North America, which need not be specially mentioned. In the case of single-phase current with series motors, good results have also been obtained in practice when several units are used with multiple-unit control, as for example at Hamburg-Altona (1) and on several American railways, for instance the Central Illinois Construction Company (2).

On the other hand with the three-phase induction motor, the speed depends upon the periodicity in conjunction with the relatively small decrease of speed for increase of load, or in other words the small amount of the slip. Thus for instance, if there are any differences in the different wheel tires or in the transmission ratios, so that equal numbers of the motors represent paths of different length, the motors will be forced to rotate at different rates; then the quicker-running machine will not do its share of the work, and even if the differences are comparatively small, if these exceed the slip, that motor may become a generator and thus overload the other motor. One of the available means for counteracting this in practice consists in compensating by rotor resistance, which, however, wastes energy. Practical experience on the Burgdorf-Thun Railway seems to show that this theoretically unavoidable disadvantage, taking the actual magnitude of the slip into consideration, does not really lead to any deleterious load fluctuations or noticeable disadvantages. On the Great Northern also, none of these disadvantages have appeared, since 1909, when using relay control on the three-phase locomotives operating the traffic; their arrangement is similar to that of the separate rail motor cars already mentioned.

Multiple-unit traction can therefore be considered feasible with all three systems, but more certainly with single-phase and direct current than with three-phase induction motors.

In addition to the requirements of railway working, as such and purely technically, which traction systems have to satisfy, these different systems have to be compared from the economical point of view. In the first place we will consider the purely technical economy, which is affected by the following points :

1° Dead weight of the traction apparatus proper;

2° Relative energy consumption and efficiency of the system;

3° Proportion of energy returned to the line;

4° Possibility of balancing the fluctuations in the load at the power stations.

The dead weight of the motors, of the whole motor equipment, and of the rolling stock. —. Formerly, the investigation of these properties was based on the ratio of the weight of the driving equipment to its (normal) output in horse-power. As opposed to this, the collaborators and members of our Commission urge that the establishment of this ratio is wrong in principle, and that it should be replaced by the ratio of the weight to the normal torque or to the normal tractive effort (1).

(1) *Elektrotechnische Zeitschrift*, 1909, p. 1043.
(2) *Street Railway Journal*, July 1907.

(1) See, for instance, *Schweizerische Bauzeitung*, 1909, vol. LIV, p. 300, and *Elektrische Kraftbetriebe und Bahnen*, 1909, p. 716.

The same result, qualitatively, is obtained by both methods; but quantitatively the ratio becomes very different.

In the article in the *Schweizerische Bauzeitung* already referred to, our collaborator, Dr. W. Kummer, has shown, by a typical example for Swiss conditions, to what erroneous conceptions an unsuitably-chosen weight ratio may lead; and that the dimensions of the rolling stock are related to the torque produced; a proportionate relation with the output can thus still be accepted as an approximation when comparing rolling stock performing similar duty, as, for example, motor-car equipments for interurban railways among themselves and for express lines among themselves, locomotives for express trains among themselves and for goods trains among themselves, etc., etc.

The peculiarities of single-phase commutator motors and the necessity of installing transformers on the rolling stock when this system is adopted, whereby it is true the best speed regulation is also obtained, at once show theoretically that the specific driving-equipment weight, viewed from both standpoints mentioned, must be greater in this case than in that of the other systems. Reliable information about driving equipments is afforded by existing undertakings. In tables A and B above, we give a number of such instances from this point of view; in them we mention the older constructions first, and the newer ones towards the end of the groups concerned.

The table shows, as was to be expected theoretically, that direct current and three-phase current are practically equal as regards weight, while the single-phase system is inferior; at the same time only unimportant differences appear in the newer installations, when compared under analogous conditions. Within one and the same system relatively important differences occur, on the other hand, due to the general progress in design, particularly as regards the size of the motors and of their equipment and the application, or non application, of artificial cooling; the latter enables the power per unit of weight to be materially increased in all three systems. A comparison with modern steam locomotives shows what a considerable reduction in weight has now already been attained as compared with steam traction.

In the case of carefully-designed modern installations, one may probably reckon with certainty on the weights given in the following tables for locomotives and for the whole electric equipment of rail motor cars when using the recognized and described means of control for the three systems quoted.

— —	Direct current.	Three-phase current.	Single-phase current.
Weight of locomotives for about 40-60 kilometres per hour.	50-55 kilograms per horse-power.	45-60 kilograms per horse-power.	50-75 kilograms per horse-power.
	11 kilograms per metre-kilogram.	10-12 kilograms per metre-kilogram.	11-13 kilograms per metre-kilogram.
Weight of rails motor-car equipments for about 40 kilometres per hour	28-30 kilograms per horse power.	30-35 kilograms per horse-power.	30-35 kilograms per horse-power.
	6-7 kilograms per metre-kilogram.	7-8 kilograms per metre-kilogram.	7-8 kilograms per metre-kilogram.

*

Table A. **Summary of chief particular**

LOCOMOTIVES.

Kind of current.	NAME OF RAILWAY.	METHOD OF DRIVE.	Characteristics, based on hour rating.						
			Speed, in kilometres per hour.	Tractive effort at wheel periphery, in kilograms		Torque, in metre-kilograms		Output, in horse-power.	
				per locomotive.	per motor.	per locomotive, at its driving axles.	per motor, at its shaft.	per locomotive.	per motor.
									Locomotives for
Direct current.	Baltimore & Ohio, 1896	Motors on axles (gearless)	24·0	16,000	4,000	12,400	3,100	1,440	360
Direct current.	Baltimore & Ohio, 1903	Toothed wheels.	17·0	13,200	3,300	7,900	450	800	200
Direct current.	North Eastern	— —	23·0	7,000	1,750	2,800	210	600	150
Direct current.	Vienna Metropolitan	— —	25·0	5,600	1,400	3,350	190	520	130
Direct current.	Michigan Central Railroad	— —	20·0	16,400	4,100	10,000	575	1,200	300
									Locomotives for
Direct current.	Paris-Orléans	Toothed wheels.	42·0	6,000	1,500	3,700	400	920	230
Direct current.	Paris-Versailles	Motors on axles (gearless)	40·0	4,000	1,000	2,600	650	600	150
Direct current.	Central London	— — —	35·0	5,600	1,400	3,000	750	720	180
Direct current.	Central London	Toothed wheels.	37·0	4,400	1,100	2,750	210	600	150
Direct current.	Milan-Varese	— —	40·0	4,000	1,000	2,800	200	600	150
									Locomotives for
Direct current.	New York Central, 6000.	Motors on axles (gearless)	64·5	9,200	2,300	5,200	1,300	2,200	550
Direct current.	Pennsylvania Railroad, 1909	Cranks and connecting rods.	48·0	23,000	11,500	20,000	10,000	4,000	2,000
									Locomotives for
Three-phase current.	Burgdorf-Thun, 1899	Toothed wheels and cranks.	18·0	4,400	2,200	2,700	360	300	150
			36·0	2,200	1,100				
Three-phase current.	Great Northern.	Double reduction gearing	24·0	21,640	5,410	16,500	950	1,900	475
Three-phase current.	Burgdorf-Thun, 1910	Toothed wheels and cranks.	15·72	8,570	4,285	2,300	145	800	400
			21·0	7,720	3,360				
			31·5	6,000	3,000				
			42·0	5,140	2,570				

isting traction equipments. Table A.

LOCOMOTIVES.

Weight of locomotive, in kilograms.						Weight of electric equipment, in kilograms.			*Remarks.*
Without carrying axles.			With carrying axles.			Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	
...ge.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.				
speeds.									
,000	7·7	67·0	...	...	...	?	?	?	Is in service at only half voltage, half speed and half power.
,000	11·4	100·0	...	...	...	20,300	2·9	26·0	
,200	20·0	94·0	...	...	...	?	?	?	
,000	8·7	56·0	...	...	...	14,500	4·3	28·0	Experimental locomotive, high-tension three-wire system.
,000	9·1	76·0	...	...	...	29,500	3·0	25·0	
um speeds.									
,000	13·5	54·5	...	...	...	21,300	5·8	23·0	
,900	19·5	85·0	...	...	...	22,000	8·5	37·0	Normal tractive effort estimated.
,300	14·8	62·0	...	...	...	24,800	8·3	35·0	
,500	11·4	53·0	...	...	...	?	?	?	
,000	12·5	58·0	...	...	...	?	?	?	
speeds.									
..	...	...	90,000	17·0	41·0	27,800	5·4	13·0	75 per cent adhesion.
..	...	...	168,000	8·4	42·0	?		?	62 per cent adhesion.
speeds.									
,000	11·1	100·0	...	...	...	10,000	3·7	33·0	
,000	7·0	61·0	...	...	...	54,000	3·3	28·0	Train transformers.
,000	18·3	53·0	...	...	...	18,000	7·8	23·0	

Table A. (*Continued.*) **Summary of chief particul**

LOCOMOTIVES. (*Continued.*)

Kind of current.	NAME OF RAILWAY.	METHOD OF DRIVE.	Characteristics, based on hour rating.						
			Speed, in kilometres per hour.	Tractive effort at wheel periphery, in kilograms		Torque, in metre-kilograms		Output, in horse-powe	
				per locomotive.	per motor.	per locomotive, at its driving axles.	per motor, at its shaft.	per locomotive.	per motor.
									Locomotives
Three-phase current.	Valtelina, type 34	Motor on axle (gearless). .	33·0	7,200	1,800	5,050	1,260	900	2
	Italian State Railway, type Giovi . .	Parallel crank drive . . .	22·0	10,300	5,150	6,000	3,000	2,000	1,0
			41·0	12,300	5,150				
									Locomotives
Three phase current.	Berlin-Zossen	Toothed wheels.	100·0	2,720	680	1,700	200	1,000	2
	Valtelina, type 36	Parallel crank drive . . .	32·0	7,800	3,900	5,800	2,900	1,200	6
			64·0	5,100	2,550				
	Valtelina, type 38	— — — . . .	25·5	9,000	4,500	6,750	3,375	1,500	7
			42·0	7,600	7,600				
			64·0	6,300	6,300				
	Simplon, type 1906	— — — . . .	35·0	5,800	2,900	4,800	2,400	1,100	5
			70·0	4,000	2,000				
	Simplon, type 1907	— — — . . .	26·0	11,500	5,750	7,200	3,600	1,700	8
			35·0	10,000	5,000				
			53·0	7,700	3,850				
			70·0	6,400	3,200				
									Locomotives
Single-phase current.	Murnau-Oberammergau, 1905 . . .	Toothed wheels.	18·0	3,000	1,500	750	75	200	1
	Murnau-Oberammergau, 1909 . . .	— —	22·0	4,200	2,100	1,050	100	350	1
	Saint-Clair Tunnel.	— —	16·0	12,600	4,200	10,000	630	750	2
	Oranienburg experimental line . .	— —	28·2	13,400	3,350	9,400	2,350	1,400	3
	Dessau-Bitterfeld, goods locomotive by Brown, Boveri & Co.	Cranks and connecting rods.	25·0	6,500	6,500	3,400	3,400	600	6

existing traction equipments. (*Continued.*)

Table A. (*Continued.*)

LOCOMOTIVES. (*Continued.*)

Weight of locomotive, in kilograms.						Weight of electric equipment, in kilograms.			*Remarks.*
Without carrying axles.			With carrying axles.						
Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	
dium speeds.									
6,000	9·1	51·0	...	...	...	31,500	6·2	35·0	
0,200	10·0	30·0	...	...	...	28,200	4·7	14·0	Greater tractive effort abnormal at greater speed.
gh speeds.									
4,000	32·0	54·0	...	...	...	28,000	16·0	28·0	Was in use only partly equipped.
...	...	...	62,000	10·6	52·0	32,000	5·5	28·0	68 per cent adhesion.
...	...	...	62,000	9·2	41·0	32,000	4·7	21·0	68 per cent adhesion.
...	...	...	62,000	12·9	56·0	29,000	6·0	26·0	71 per cent adhesion.
68,000	9·5	40	...	...	...	35,000	4·9	21·0	
w speeds.									
20,000	27·0	100·0	...	...	...	10,000	13·3	50·0	
24,000	23·0	69·0	...	...	...	11,600	11·0	33·0	
62,000	6·2	83·0	...	...	...	?	?	?	
67,000	7·1	48·0	...	...	...	?	?	?	Is in use only partly equipped.
56,000	16·5	93·0	...	...	...	26,000	7·6	43·0	

Table A. (*Continued.*)

Summary of chief particul

LOCOMOTIVES. (*Continued.*)

Kind of current.	NAME OF RAILWAY.	METHOD OF DRIVE.	Characteristics, based on hour rating.						
			Speed, in kilometres per hour.	Tractive effort at wheel periphery, in kilograms		Torque, in metre-kilograms		Output, in horse-powe	
				per locomotive.	per motor.	per locomotive, at its driving axles.	per motor at its shaft.	per locomotive.	per
									Locomotives
Single-phase current.	Seebach-Wettingen, No. 1-2.	Toothed wheels and cranks.	40·0	3,400	1,700	1,700	280	500	2
	Seebach-Wettingen, No. 3	Toothed wheels.	45·0	8,100	1,350	4,450	200	1,350	2
	Experimental locomotive « General Electric Company ».	Cranks and connecting rods.	32·0	13,600	6,800	8,500	4,250	1,600	8
	Berner Alpenbahn, type Oerlikon.	Toothed wheels and cranks.	42·0	12,800	6,400	8,650	1,330	2,000	1,0
	Berner Alpenbahn, type A. E. G.	Cranks and connecting rods.	40·0	10,800	5,400	6,860	3,430	1,600	8
	Midi of France, type A. E. G.	— — —	45·0	9,000	4,500	6,100	3,050	1,500	7
	Midi of France, type Brown.	Parallel crank drive	45·0	9,000	4,500	7,200	3,600	1,500	7
	Midi of France, type Thomson & Winterthur.	Cranks and connecting rods.	45·0	9,000	4,500	5,900	2,950	1,500	7
									Locomotives
Single-phase current.	New York, New Haven & Hartford, express train.	Motor on axle (gearless).	68·0	4,000	1,000	3,200	800	1,000	2
	New York, New Haven & Hartford, passenger and goods trains.	Toothed wheels and hollow shaft.	56·0	7,000	1,750	5,600	600	1,400	3
	Pennsylvania Railroad, type 10,003.	Motor on axle (gearless).	83·0	3,200	1,600	3,000	1,500	1,000	5
	Wiesental line, Siemens locomotive.	Cranks and connecting rods.	61·0	4,200	2,100	2,500	1,250	950	4
	Wiesental line, passenger locomotive by Brown, Boveri & Co.	Parallel crank drive	61·0	4,200	2,100	2,940	1,470	950	4
	Paris-Lyons-Mediterranean, type Alioth.	Toothed wheels.	60·0	8,000	2,000	6,000	500	1,800	4
	Dessau-Bitterfeld, express locomotive.	Cranks and connecting rods.	85·0	2,850	2,850	2,300	2,300	900	9

of existing traction equipments. (*Continued.*) **Table A.** (*Continued.*)

LOCOMOTIVES. (*Continued.*)

Weight of locomotive, in kilograms.						Weight of electric equipment, in kilograms.			*Remarks.*
Without carrying axles.			With carrying axles.						
Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	Total.	Per metre-kilogram of torque.	Per horse-power of output of locomotive.	Total.	Per metre kilogram of torque.	Per horse power of output of locomotive.	
medium speeds.									
42,000	24·0	84·0	...	...	...	21,000	12·0	42·0	
75,000	17·0	56·0	...	...	...	33,000	7·4	24·0	Was in use only partly equipped.
...	...	...	113,000	13·0	71·0	?	?	?	Is in use only partly equipped.
86,000	10·0	43·0	...	...	...	42,000	4·9	21·0	
...	...	...	93,000	13·5	58·0	50,000	7·3	31·0	73 per cent adhesion.
...	...	...	83,000	13·6	55·0	?	?	?	70 per cent adhesion.
...	...	...	80,000	11·1	53·0	42,000	5·8	28·0	68 per cent adhesion.
...	...	...	86,000	14·5	57·0	46,000	7·8	31·0	63 per cent adhesion.
high speeds.									
77,000	24·0	77·0	...	...	...	?	?	?	
...	...	...	118,000	21·0	84·0	?	?	?	72 per cent adhesion.
...	...	...	65,250	22·0	65·0	?	?	?	
...	...	...	68,600	27·0	72·0	?	?	?	67 per cent adhesion.
...	...	...	65,000	22·0	69·0	31,000	10·5	33·0	65 per cent adhesion.
...	...	...	136,000	22·0	76·0	72,000	12·0	40·0	53 per cent adhesion. Transformer locomotive.
...	...	...	60,000	26·0	67·0	?	?	?	47 per cent adhesion.

Table B. **Summary of chief particulars of existing traction equipments.** (*Continued.*)

RAIL MOTOR CARS.

Kind of current.	NAME OF RAILWAY.	Gear ratio.	Characteristics, based on hour rating.								Weight of electric equipment, in kilograms			*Remarks.*
			Speed, in kilometres per hour.	Tractive effort at wheel periphery, in kilograms		Torque, in metre-kilograms		Output, in horse-power		Total.	per metre-kilogram of torque of car.	per horse-power of output of car.	
				per car.	per motor.	per car at its driving axles.	per motor, at its shaft.	per car.	per motor.				
Rail motor-cars for low speeds.													
Direct current.	Freibourg-Murten-Ins.	1:4·0	21	5,000	1,250	2,500	160	400	100	12,000	4·8	30	
	Tabor-Bechyne	1:5·0	17	1,900	475	800	40	120	30	5,300	6·6	44	Distribution on the three-wire system.
Rail motor-cars for medium speeds.													
	Lancashire & Yorkshire Railway, car with two motors.	1:2·15	32	2,100	1,050	1,120	260	250	125	7,000	6·2	28	
	Lancashire & Yorkshire Railway, car with four motors.	1:1·95	32	5,000	1,250	2,670	340	600	150	17,000	6·4	28	
	Paris-Versailles, car with two motors.	?	45	1,800	900	765	?	300	150	6,500	8·5	22	
	Paris-Versailles, car with two motors.	?	45	1,900	475	1,000	?	320	80	11,000	11·0	34	

	Milan-Varese, car with two motors	1:2·5	43	1,900	950	1,000	200	300	150	6,500	6·5	22	
	Milan-Varese, car with four motors	1:2·5	43	3,800	950	2,000	200	600	150	12,000	6·0	20	
	North Eastern	1:3·24	29	2,800	1,400	1,300	200	300	150	6,300	4·8	21	
Rail motor-cars for medium speeds.													
Three-phase current.	Burgdorf-Thun	1:3.0	36	1,800	450	920	77	240	60	10,000	10·9	42	
	Valtelina	1:1	32 64	2,000 1,260	500 320	1,170	290	300	75	23,000	19·7	77	
Rail motor-cars for very high speeds.													
Three-phase current.	Berlin-Zossen, AEG-car	1:1	210	2,300	575	1,440	360	1,800	450	29,870	20·0	16	
Rail motor-cars for low speeds.													
Single-phase current.	Murnau-Oberammergau	1:5·0	20	3,600	900	1,800	90	200	100	11,700	6·5	59	
Rail motor-cars for medium speeds.													
Single-phase current.	Johannistal-Spindlersfelde	1:4·0	38	1,800	900	900	112	250	125	6,000	6·7	24	Without transformer.
	Vienna-Baden	1:3·2	40	1,100	275	470	37	160	40	10,500	24·5	66	Both for single-phase and for direct current.
	Midland Railway, Siemens-car	1:3	32	3,300	1,650	1,800	300	400	200	19,000	10·5	47	
	Midland Railway, Westinghouse-car.	1:2·8	32	2,500	1,250	1,400	250	300	150	15,000	12·0	50	
	Hamburg-Altona	?	28	3,500	1,750	1,750	?	360	180	12,500	7·2	35	

With regard to the least possible dead weight of driving equipment carried, we may at once state that all three available systems are immeasurably superior to steam traction. Direct current and three-phase current for locomotives are, when compared with each other, practically equal in this respect and single-phase current is probably inferior by about 20 per cent; for rail-motor-car operation, three-phase and single-phase current are about equal, direct current being about 5 per cent better. It must, however, not be forgotten that the percentage difference of weight of the electric driving equipment makes only a small difference in the total weight of the train, and that the somewhat greater weight of the single-phase system corresponds to better regulating conditions.

Relative energy consumption and efficiency of the systems. — As regards the efficiency generally in the case of electric operation, the chief factor is the efficiency of the motors, which depends wholly on the system and can only be improved within certain limits. Minor factors are the efficiencies of the transformer, generator and converter installations, and these can be much improved by suitable design, by having fewer units, but these of larger size. It is technically possible to make the efficiency of the whole distribution very high. Any comparison between the different systems must therefore be based both on the efficiency of the distribution and of the whole installation, and on the cost of operation, maintenance and of the capital charges. This must not be forgotten when comparing the efficiencies, as these taken alone are not decisive.

As regards the motor efficiency attained (measured by the ratio of the energy delivered at the periphery of the wheels to that received at the motor terminals; in the case of single-phase and multiphase motors, the power factor must also be taken into consideration), particulars about a number of railway motors of different systems, built in Switzerland, are given in the following table. It is to be particularly noted that all systems referred to in the following tables are of the kind in which the speed regulation is accomplished without any additional loss in the regulating apparatus. With direct current, this speed regulation is dependent on the existence of a sufficiently large number of motors on the car to make it possible to have effective series-parallel control; in addition, the shunting of the magnet windings for immediate points is necessary; in the above case a four-motor equipment is assumed. With three-phase current, the regulation is accomplished by means of commutating poles; and with single-phase current, in the case of Déri motors, by shifting the brushes, and in the case of series motors by regulating the voltage by means of the main transformer which is always available.

The following table refers to those motors which have already been given as examples.

With a direct-current motor, type G. T. M. 65 of the Alioth Electrical Co., with an hour rating of 66·5 horse-power, when running at 45 kilometres (28 miles)

per hour and giving a normal tractive effort of 400 kilograms (880 lb.) at the periphery of the wheels, the efficiencies are as follows :

Efficiencies, per cent, when running at different speeds.

—	With tractive efforts, in kilograms, of					
	100	150	200	300	400	500
At speeds, in kilometres per hour of 11·25	72·5	72·9	71·5	69·2	64·0	61·3
At speeds, in kilometres per hour of 16·85	75·5	76·6	76·4	75·2	72·6	69·0
At speeds, in kilometres per hour of 22·5	77·5	78·5	79·1	80·6	67·5	73·5
At speeds, in kilometres per hour of 33·7	79·1	81·0	82·0	82·5	81·0	98·4
At speeds, in kilometres per hour of 45·0	80·0	82·0	83·0	84·0	83·2	81·5
At speeds, in kilometres per hour of 56·25	81·0	83·4	84·5	85·5	84·5	83·0

With a three-phase induction motor with commutation of poles (changing of pole connections) type D. 16/6-500-320 of Brown, Boveri & Co., with an hour rating of 650 horse-power when running at 74 kilometres (46 miles) per hour, and giving a normal tractive effort of 2,400 kilograms 5,290 lb.) measured at the periphery of the wheels, the efficiencies and power factors are as follows :

Efficiencies, per cent, when running at different speeds.

—	With tractive efforts, in kilograms, of					
	600	900	1,200	1,800	2,400	3,000
At speeds, in kilometres per hour of 27·5	80·0	84	85	85·5	84	81·5
At speeds, in kilometres per hour of 37·0	84·5	87	88	87·5	85	80·0
At speeds, in kilometres per hour of 55·0	86·0	87	88	85·0	89	87·0
At speeds, in kilometres per hour of 74·0	89·0	91	90	90·5	89	87·0

Power factors when running at different speeds.

—	With tractive efforts, in kilograms, of					
	600	900	1,200	1,800	2,400	3,000
At speeds, in kilometres per hour, of 27·5	0·36	0·50	0·59	0·71	0·80	0·82
At speeds, in kilometres per hour, of 37·0	0·50	0·61	0·70	0·795	0·82	0·82
At speeds, in kilometres per hour, of 55·0	0·80	0·86	0·895	0·91	0·90	0·91
At speeds, in kilometres per hour, of 74·0	0·88	0·905	0·935	0·905	0·91	0·915

With a single-phase commutator motor with Déri control, type E 12-450-250 of Brown, Boveri & Co., with an hour rating of 345 horse-power when running at

74 kilometres (46 miles) per hour, and giving a normal tractive effort of 1,260 kilograms (2,778 lb.) measured at the periphery of the wheels, the efficiencies and power factors are as follows :

Efficiencies, per cent, when running at different speeds.

—		With tractive efforts, in kilograms, of					
		315	472	630	945	1,250	1,575
At speeds, in kilometres per hour, of	18·5	70	66	64	65	60	50
	28·0	71	72	73	74	70	63
	37·0	72	78	79	82	78	75
	55·5	73	84	87	92	92	91
	74·0	74	84	87	90	90	82
	92·5	66	76	80	88	80	60

Power factors when running at different speeds.

—		With tractive efforts, in kilograms, of					
		315	472	630	945	1,260	1,575
At speeds, in kilometres per hour, of	18·5	0·38	0·45	0·50	0·55	0·60	0·70
	28·0	0·45	0·53	0·58	0·63	0·68	0·77
	37·0	0·52	0·59	0·65	0·71	0·76	0·82
	55·5	0·64	0·70	0·76	0·84	0·88	0·89
	74·0	0·85	0·80	0·85	0·90	0·91	0·89
	92·5	0·84	0·87	0·90	0·89	0·85	0·81

With a single-phase series motor type 12 WB 1000 of the Oerlikon Co., with an hour rating of 1,000 horse-power when running at 42 kilometres (26 miles) per hour, and giving a normal tractive effort of 6,400 kilograms (14,110 lb.) measured at the periphery of the wheels, the efficiencies and power factors are as follows:

Efficiencies, per cent, when running at different speeds.

—		With tractive efforts, in kilograms, of					
		1,600	2,400	3,200	4,800	6,400	8,000
At speeds, in kilometres per hour, of	10·5	76	77	77	78	78	77
	16·0	79	80	81	82	83	82
	21·0	82	83	84	85	85	84
	32·0	83	84	85	86	86	85
	42·0	84	86	87	87	87	86
	52·5	85	86	87	88	88	87
	70·0	87	88	89	89	89	88

Power factors when running at different speeds.

—		With tractive efforts, in kilograms, of					
		1,600	2,400	3,200	4,800	6,400	8,000
At speeds, in kilometres per hour, of	10·5	0·60	0·60	0·60	0·60	0·60	0·60
	16·0 . .	0·75	0·75	0·75	0·75	0·75	0·75
	21·0 . . .	0·86	0·86	0·86	0·86	0·86	0·86
	32·0	0·92	0·92	0·92	0·92	0·92	0·92
	42·0	0·96	0·96	0·96	0·96	0·96	0·96
	52·5	0·965	0·965	0·965	0·965	0·965	0·965
	70·0 . . .	0·97	0·97	0·97	0·97	0·97	0·97

The examples given are based on the use of single spur gear with the direct-current motors, parallel crank drive with the three-phase and the Déri motors, and spur gearing and coupling-rod drive with the single-phase motor.

When the different sizes and the various methods of drive for these motors are considered, it is apparent that the single-motors have quite held their own in efficiency as compared with three-phase induction and direct-current series motors. Comparisons of efficiency curves of larger motors, such as are normally used for railway locomotives, show that with such direct-current and three-phase motors of modern build, efficiencies of 0·90 to 0·93 can be reckoned on at full load, and with the corresponding single-phase motors, the efficiency is at the worst 3 to 4 per cent less. As against this, the smaller power factor of all alternating-current systems, as compared with direct current, is a disadvantage as regards the distribution and the supply of power; with the single-phase series motor the power factor is always larger than with the three-phase and other alternating-current motors. But as much higher contact-line voltages can be used with alternating-current systems generally, and especially with single-phase current, than with direct current, the presence of a smaller power factor entirely loses its importance as regards the distributing system, at least in the case of single-phase current.

Moreover, with direct-current motors and three-phase induction motors, the use of resistance in addition to step control, even while running and for considerable periods of time, cannot as a matter of fact be avoided under certain conditions, and these resistances cause a considerable loss, so that the over-all efficiency is materially reduced. Consequently, every advantage of the direct-current system over the alternating-current system disappears from the standpoint of efficiency and volt-ampere input and even the three-phase current is in these respects inferior to the single-phase current. With the most recent three-phase current equipments for large motors, namely for the locomotives of the Simplon, commutation of poles (changing of pole connections) alone, without rotor resistances, has undoubtedly been successful and consequently in such cases, the above-mentioned disadvantage does not arise in the case of three-phase current.

If we examine the case of starting, those conditions, lasting only a short time, do not it is true materially affect the efficiency of the system taken over longer periods; the difference between the three systems is however similar, but more marked.

Practical measurements of the efficiency of the entire traction equipment and of the control mechanisms, or the efficiency of whole trains, should confirm these theoretical considerations. Such determinations would be of great value, as they alone clearly show what the actually-existing mean loads of the motors and efficiencies of the controlling arrangements are. We have collected a number of such examples from measurements made during actual running. Great care must however be taken in using such figures, and only that amount of importance is to be attached to them which circumstances justify. The peculiar conditions of traction and profile of the railway under consideration are very important factors; to get comparative results free from objection, it would be necessary to operate one and the same railway under like conditions by means of the different systems consecutively, and while doing so to be able to take measurements. The results given are therefore only to be considered in this limited sense as of any importance.

Special experiments were made on the Freiburg-Murten and the Burgdorf-Thun lines in order to determine the loss in the regulating rheostats. In the former case, the train was equipped at that time only with two direct-current motors of 200 horse-power each; the loss on the round trip amounted to about 13 per cent of the total energy received by the train. In the latter case, three-phase induction motors without changing of connections of poles were used; the corresponding loss was about 14 per cent. At the very least, this shows that a system which eliminates such resistances is all the better for doing so. (It is to be noted, with regard to the Freiburg-Murten Railway, that the rail motor cars now each have an equipment of four 100-horse-power motors, so that the figure given bears no relation to the new equipment described in the third part of this report.)

In the annexed table C giving the results of trials concerning the energy consumption and efficiency of actual installations, the latter could be given only inclusive of the contact-line loss, that is to say, as between the wheel periphery and the feeding point of the contact line; we have also given, as far as possible, the inclusive efficiency of the distribution from the power station (between the current supplied at the power station and the equivalent received at the periphery of the wheels); besides, the efficiency of transformation could be given in a few cases, as well as the actual energy consumption per unit of load carried, to which we will refer later on.

In the determination of the efficiencies in this table, the magnitude of the rolling resistance had to be assumed in most cases for want of actual experiments. This was done as carefully as possible, taking into consideration the results available and the particular conditions of the railway, as regards speeds, gradients, curves, and construction of permanent way; the assumed value is given in the table. The efficiencies given in each case are those for a whole train trip or for longer distances,

C. — Table of power absorbed and of efficiency.

RAILWAY.	Rolling resistance taken as basis.	Power consumed, in watt-hours per ton-kilometre.			Efficiency			*Remarks.*
		calculated at wheel periphery.	measured at feeding point.	measured at power station.	wheel periphery to feeding point.	wheel periphery to power station.	of transformation.	
Direct current.								
Milan-Varese-Porto-Ceresio	5	32·7	...	42	...	0·54	...	Transformation, with batteries, speed, up to 50 kilometres per hour.
Paris-Orsay to Paris-Austerlitz	4	19·7	28·4	36·5	0·69	0·54	0·78	40-50 kilometres per hour.
Paris-Austerlitz to Juvisy	6	29·8	39	52·3	0·77	0·57	0·74	Up to 75 kilometres per hour.
Paris-Versailles	5	30·2	43	61·5	0·70	0·49	0·70	Transformation, without batteries, up to 55 kilometres per hour.
Paris Metropolitan	5	48·5	70·5	79·3	0·69	0·61	0·89	Transformation, with batteries.
Liverpool (Merseytunnel)	5	46·3	66·5	66·5	0·695	...	...	Direct current supplied direct.
Lancashire & Yorkshire Railway (Liverpool-Southport)	Express trains 6 Passenger stopping trains 5	19·1	23·5	...	0·81	...	...	Up to 90 kilometres per hour.
		36·3	49	...	0·74	...	...	Up to 60 kilometres per hour.
North Eastern	...	...	37·7	43·3	...	...	0·87	Transformation, without batteries, and without long-distance transmission of high voltage.
Freiburg-Murten-Ins	5	29	44	...	0·66	...	...	Up to 40 kilometres per hour.
Berlin-Grosslichterfelde (East)	5	28·5	37·4	37·4	0·76	...	...	Direct current supplied direct, speed up to 50 kilometres per hour.
Saint-Georges-La Mûre	7	46·2	59	...	0·78	...	...	Direct current, supplied direct.
Neuchâtel-Cortaillod-Boudry	7	30·5	...	48	...	0·64	...	Transformation, with batteries.
Montreux-Bernese Oberland	7	55·2	...	124	...	0·46	...	
St-Gallen-Trogen	8	77·2	109	138	0·72	0·56	0·79	Transformation, without long-distance high-tension transmission.
Three-phase current.								
Burgdorf-Thun	4	28·6	42·1	...	0·68	...	...	Rail motor car.
	4	28·6	42·5	...	0·67	...	...	Locomotive.
	4	28·6	...	93·6	...	0·31	...	Measurement on one day.
	4	28·6	...	68	...	0·42	...	Measurement on one day.
Valtelina	5	20	...	58	...	0·345	...	According to diagram.
	5	20	...	(44·5)	...	0·45	...	
	5	17	...	35	...	0·485	...	Single trips.
	5	20	31	...	0·65	...	...	
Stansstad-Engelberg	7	55·5	...	115	...	0·483	...	Partly simple transformers, metre-gauge track.
Single-phase current.								
Murnau-Oberammergau	4	29·2	...	43	...	0·68	...	Without transformers, up to 20 kilometres per hour.
Seebach-Wettingen (trials runs) (actual service)	5	18·5	...	29·2	...	0·63	...	Transformer locomotive; locomotive with motors with commutators, and with transformers.
	5	17·7	25	...	0·71	...	...	
	5	20·8	30	...	0·70	...	...	
Stubaithal	8	49	70	...	0·70	...	...	Metre gauge.
Maggiathal	7	31·3	...	51·8	...	0·60	...	Without transformers, metre gauge.
	7	31·3	...	53·2	...	0·59	...	

that is for the total work or energy. In the case of the railways using three-phase current, the losses in the contact line and rails were not (as in the other cases) measured directly at the same time, so that these must be deducted in these cases; special determinations showed that they amounted to from 6 to 7 per cent on the Burgdorf-Thun Railway, so that the efficiency measured must be multiplied by 0·94. Then also the energy generated when running downhill has not been deducted from that used; if this can be utilized for trains running at the same time, then, according to a special trial made on the Burgdorf-Thun Railway, about 20 per cent less energy can be supplied to the trains, and the efficiency of the system has to be multiplied by the factor $\frac{1}{0{\cdot}8}$. In the case of the measurements on the Burgdorf-Thun Railway, which refer to the efficiency between power station and wheel periphery, for long periods of working, the energy returned to the line when running downhill is however taken into account.

From this table C, it can at least be concluded that the average efficiency of trains may be considered in the case of newer installations of the systems used as :

—	Direct current.	Three-phase current.	Single-phase current.
Without recovery of energy on down gradients . . .	0·70-0·80	0·65-0·70	0·70-0·75
With recovery of energy on down gradients	...	0·68-0·85	0·70-0·87

It has already been mentioned that the efficiency of the contact line depends on the expenditure incurred, and hence can be determined in accordance with economical considerations. It has also to be remembered that the voltage drop must be kept within smaller limits in the case of direct-current and especially of three-phase induction motors with direct feeding by means of the contact line, than in that of single-phase current, as long as a step-down transformer is used in this case (as it always will be) for regulating the voltage. In the case of long-distance transmission to the feeding points or transformer substations the efficiencies of all three systems are equal.

The most important factor in the efficiencies is the installation for the transformation of the current in the broadest sense of the word. In the case of the direct-current system, it consists of a station with rotary converters for high-tension three-phase to direct current, with or without balancing batteries. Experience shows that the yearly efficiency, according to the conditions, fluctuates from about 0·65 to 0·85. The figures in our table come within these limits. It also appears that the improvement obtained in the mean efficiencies of the generating groups by the use of balancing batteries, is approximately compensated by the losses in the batteries themselves.

In the cases of three-phase current and of single-phase current the installation required at the substations merely reduces the voltage and these are transformer substations properly so-called. The energy losses are small in the copper, and very large in the iron; for the latter, which represent the no-load losses, are of con-

stant magnitude. The trials made on the Burgdorf-Thun Railway show no-load losses of 40 per cent of the yearly energy, and those of the Valtelina line 55 per cent. It must not be deduced from this that such large losses in the static transformers have always to be allowed for in the case of three-phase railways or even in that of single-phase railways. The higher the contact-wire voltage used, the fewer can be the number of feeding stations, and the better will be the utilization of the energy supplied on the section between these stations; the smaller the total capacity and the larger the individual transformers are the smaller the consequent losses; these losses consequently are smaller with single-phase current than with three-phase current, as a higher voltage can be used in the contact wire. In addition, these losses will be very much reduced by using better material for the laminations in the transformers (the trials quoted refer to older transformers). In this connection, it may be noted that the new laminated plates used for 50 periods, with 10,000 lines of force per square centimetre (64,514 lines per square inch) and 0·5 millimetre (0·02 inch) thick, can now be regularly supplied with a loss index of 1·85 watts per kilogram (0·84 watt per lb.), while this index has a value of 3·8 watts per kilogram (1·72 watts per lb.) in the case of ordinary plates.

All these considerations and especially existing experience permit us, in a comparison of the systems with reference to the efficiencies, to conclude that approximately the following may be taken, as the efficiencies of the three systems under average conditions :

—	Direct current.	Three-phase current with recovery.	Three-phase current without recovery.	Single-phase current with recovery.	Single-phase current without recovery.
Trains	0·75-0·80	0·68-0·85	0·68	0·70-0·87	0·70-0·75
Contact lines and rails	0·90-0·94	0·90-0·94	0·90-0·94	0·90-0·94	0·90-0·94
Transformers on locomotives . .	0·75-0·90	...	...	...	...
Transformers :					
Losses at no-load	...	0·75-0·70	0·75	0·85-0·80	0·85
Losses in copper	...	0·94-0·96	0·94-0·96	0·94-0·96	0·94-0·96
High-voltage transmission . . .	0·90-0·95	0·90	0·90	0·90	0·90
Whole system	0·45-0·64	0·39-0·48	0·39-0·41	0·45-0·56	0·45-0·52

According to the above, if the transformer stations are well loaded, the direct-current system will show the best efficiency, and the three-phase system the worst.

The specific energy consumption per unit of load hauled, as actually observed when electric traction is used, can give direct information about the technical value and the efficiency of a whole system only when figures are compared which are based upon similar running conditions (particularly with regard to speeds, gradients, number of stops, etc.). We have likewise given in our table these figures as they were actually measured from the output of the power stations of several railways; on the whole, they only show

how much these values vary with the conditions, without affording definite conclusions as to the efficiencies.

The much-disputed question of energy recovery has, in general, no particular importance, according to our investigations; this is already made evident by the figures in our table; we will however refer to this matter again.

The possibility of balancing the fluctuations in the load. — This point is of great importance in the design of power stations, particularly in Switzerland, where electrification is desired in order to make it possible to utilize the water-powers existing in the country. The ideal conditions for electric operation would be to have the whole traffic load equally distributed over the whole time, by having many similar trains; the only fluctuations in the load would then result from the gradients. But no railway will be able to attain these ideal conditions. We, like others, have on our main railroads the difficulty of times of congestion with heavy and fast express trains, which at times make a very large supply of power necessary. The relation between the maximum and mean loads required will vary within very wide limits according to the size, the amount of traffic and the profile of a section or district, and that system will be of greatest advantage to us, which technically, and more particularly economically, can balance these fluctuations most easily, so as to give minimum difficulties to the water-power plant.

In studying these relations, the first thing necessary is the determination of the ratio of the maximum load required to the mean load, for the network of railway lines considered.

It is clear that this ratio decreases as the size of the network increases. Its value is of importance as regards networks of such a size as to be fed from one feeding point (transformer station, substation), and also as regards the big networks which are supplied by one and the same power station. As but few practical results were available, our collaborator, Mr. L. Thormann, has tried to calculate these ratios by means of load diagrams for individual sections of our railways. In order that the work should not be too complicated, definite assumptions were made as to the maximum number of optional trains running simultaneously, the maximum train weights occurring simultaneously, number and location of simultaneous starts, etc. The assumptions made in any case somewhat exceed the maximum which could ever occur in practice, but otherwise are based on the existing time-tables of the Swiss Federal Railway. These assumptions served as basis in calculating these ratios, as given in the annexed table, for networks of different sizes, the sizes being characterized by the mean number of ton-kilometres of haulage per day; in determining these ratios a large number of individual cases were worked out. We add the results obtained on electric railways in operation, some of which it is true work under conditions very different from those on normal railways.

As regards the computed figures, it must be added that the duties, on which the mean loads were based, were taken from the mean traffic of the whole year, while the maxima represent the maxima

of the heaviest load of individual days, so that the heaviest load of the worst day is compared with the mean load of average days, while with the observed values of other railways, the ratios are based on the work and maximum load of the same day. Thormann's ratios may therefore be considered a maximum, which will rarely be reached even under our conditions which owing to circumstances and owing to the unavoidable time-table arrangements, are of themselves already unfavourable.

Ratio of maximum output required to mean output during working hours.

Network with a traffic load, in ton-kilometres per day, of	Number of simultaneous trains.	Number of working hours per day.	Output in kilowatts		Ratio of maximum output to mean.
			maximum.	mean.	
a) Calculated under the most unfavourable conditions for a portion of the Swiss railway system (output at wheel periphery).					
500,000 to 1,000,000	...	...	...	...	3·8 to 6·8
1,000,000 to 1,500,000	...	...	..	...	3·5 to 5·2
1,500,000 to 2,000,000	...	...	..	...	4·0 to 4·8
2,000,000 to 3,000,000	...	..	...	...	3·2 to 4·0
3,000,000 to 5,000,000	...	...	...	...	3·3 to 4·0
5,000,000 to 10,000,000	...	...	...	..	3·3 to 4·2
10,000,000 to 30,000,000	...	...	...	...	3·15
b) Observed in the case of existing railways (output at power station).					
Neuchâtel-Cortaillod-Boudry	12,000	4-5	18	260	35	7·4
Burgdorf-Thun	70,000	3-4	19	1,000	266	3·8
Valtelina line	264,000	6-7	20	2,200	760	2·9
Le Fayet-Chamonix	?	?	18	594	167	3·6
North Eastern Railway Newcastle (Central) to Carville.	500,000	20	?	4,500	2,700	1·66
Paris Metropolitan (the various substations)	1,943,000	10-22	20	...	...	1·75 2·4

Our collaborator, Dr. W. Kummer, has recently made a new series of computations, applying to the whole system of the St. Gothard Railway. A very accurate method of calculation was used. The annual traffic was assumed to be 30 per cent greater than in 1907, which so far has been the busiest year (1,436 million ton-kilometres [878,212,000 English ton-miles], gross, hauled). The ratio of the fluctuations of load, measured at the periphery of the wheels (maximum on busiest day to yearly average), was 3·0 for the whole system, the traffic on the busiest day being assumed to be 1·5 times that of an average day; if for purposes of operation the system is divided into two separate sections, north and south of the

St. Gothard, then the corresponding ratios in these separate districts would be about 3·7 and 3·3 in the north and south respectively.

On the basis of Thormann's figures, the conditions of the various possibilities of balancing by storage were considered for the systems under review. Apart from the storage of energy effected by the rotating masses on the generators and the kinetic energy of the moving trains, which is only of theoretical interest but of no importance in practice, balancing can be effected only by means of electric storage batteries or by means of hydraulic (accumulator) stations. Balancing by means of storage batteries is conceivable, at the contact wire, in the case of direct current, by using every transformer sub-station for converting three-phase into direct current, and also as a storage point with an accumulator battery; or by arranging a "central" balancing station at intermediate point which feeds several sub-stations, and is thus placed within the high-tension three-phase current system. In the latter case, the ratio between maximum and mean loads becomes smaller, and the same applies to the battery and to the loss in the energy it has to store; on the other hand, special generators are necessary for supplying the substations, as is always the case when balancing in the contact wire is adopted in the case of the three-phase or the single-phase system; the central balancing station must be equipped with converters from three-phase or single-phase current to direct current, kept running constantly for feeding the battery. If, on the other hand, the three-phase or single-phase current is not delivered by the power station at the proper periodicity, motor generators must also be used in this central balancing station to transform the periodicity, to which it is merely necessary to couple a direct-current generator.

Balancing by water storage is likewise applicable to all kinds of current supply. It must be possible, in this case, to arrange a storage reservoir at a great height; high-voltage motors are used to drive centrifugal pumps which, running at a uniform rate, will do the amount of work (taking the degree of efficiency into consideration) corresponding to the excess beyond the mean requirements of the railway system; while a high-pressure turbine coupled to a generator will provide for the constantly-changing excess over actual requirements. With this method of balancing the efficiencies of the turbines at no load are of special importance.

In our studies of the problem of balancing, special conditions for an ideal railway system were assumed, which approximated to those existing on our Swiss Federal Railway. Estimates were worked out for the erection of the necessary works, and the annual expenditure for staff, upkeep, interest and depreciation was determined for the various cases considered. The outputs and powers to be delivered to the contact line, were assumed, in the interests of simplicity and uniformity, to be of the same magnitude for all the different systems of current; in addition, the same probable price of the high-tension energy supplied, and also the same very high ratio of maximum to mean load, 4 : 1, were assumed in all cases. The comparison between the different current-systems using battery storage was made twice for the same net-

work; once for traffic of medium density such as occurs on the Swiss Federal Railway (traffic 672,000 ton-kilometres [410,974 English ton-miles] per day); and once for traffic of great density, such as only occurs at times of greatest loads and on the busiest lines of the Federal railways. The results can not serve for the determination of the absolute costs, as the figures obtained only refer to the particular conditions of an ideal case; they can however be used for a comparison of the different systems, and will then probably enable us to draw correct conclusions, as far as our conditions are concerned; for the ideal case considered was made to approximate to these as far as was practicable. The results obtained are given in the following tables:

Traffic of medium density.
(672,000 ton-kilometres per day.)

—	When using:		
	Direct current at 3,000 volts, separate storage points.	Three-phase current at 5,000 volts, central storage, without transformation of periodicity.	Single-phase current at 15,000 volts, central storage.
Number of kilowatt-hours supplied by the high-tension power distribution, for every kilowatt-hour taken from the contact line.	1·54	1·65	1·65
The relative cost of the energy thus taken is therefore	100 per cent.	107 per cent.	107 per cent.
The corresponding cost of transformation is . .	136 —	93 —	68 —
Consequently the cost per kilowatt-hour delivered is	236 —	200 —	175

Traffic of great density.
(1,700,000 ton-kilometres per day.)

—	When using:		
	Direct current at 3,000 volts, separate storage points.	Three-phase current at 5,000 volts, central storage, without transformation of periodicity.	Single-phase current at 15,000 volts, central storage.
Number of kilowatt-hours supplied by the high-tension power distribution, for every kilowatt-hour taken from the contact line.	1·40	1·55	1·50
The relative cost of the energy thus taken is therefore	100 per cent.	111 per cent.	107 per cent.
The corresponding cost of tranformation is . .	64 —	50 —	43 —
Consequently the cost per kilowatt-hour delivered is	164 —	161 —	150 —

(Analogous comparative calculations had shown, that direct current, isolated storage was more advantageous than central storage, consequently the former only is given here.)

It accordingly appears that of the three systems used in practice, the single-phase system gives the best and the direct-current system the worst results, from the point of view of the balancing action of storage batteries.

In a similar manner, a comparison was made between accumulator storage and water storage, the results of which naturally cannot be thoroughly conclusive, because the cost of hydraulic storage depends too much upon the local conditions. Besides this, very few reliable data are available concerning the no-load water consumption of turbines, and its variation with the allowable wear of the wheels. The figures available refer mostly to smaller turbines of older construction, which certainly were built without paying special attention to the reduction of the no-load losses. Thus our comparison had to assume a water consumption at no-load of 20 per cent of that required by the turbines at full load; to this must be further added about 5 per cent for the constantly-running generator when working at no load. Under these unfavourable conditions for water storage, a comparative calculation analogous to that for electric accumulator storage showed, for a small storage installation of 500 kilowatts mean load and 2,000 kilowatts maximum load, and a head of water of 200 metres (656 feet) in the case of operation with 15,000-volt single-phase current on the contact wire, that the costs, per kilowatt hour delivered, with accumulator storage and with hydraulic storage were about in the ratio of 1 : 1·2, when the single-phase current was supplied directly as such, and also when it had to be transformed from three-phase current in the storage station. It was further noted that this ratio did not materially change, other conditions being equal, when direct current or three-phase current was used instead of single-phase current for the contact-wire distribution; that, on the contrary, the cost ratio between the two methods of storage was accentuated, when the ratio of maximum to average load was increased. There is probably no doubt that for the smaller values of this latter ratio (which will generally be in question), the difference of cost of the two systems of storage becomes materially smaller, and sometimes disappears, when using newer turbines especially designed for small no-load losses; in fact it might even become negative, so that hydraulic storage would then become economically superior to battery storage.

As regards the question of system, the investigations of the storage conditions shows that that in this respect the single-phase system is better than the three-phase system, and the latter better than the direct-current system. And this is so under the assumption taken as basis in this investigation, namely that with all the three systems the same quantity of energy is taken from the contact line. This involves that in the case of three-phase operation, regulation will always be possible by the use of cascade coupling, so that the speed on gradients can be reduced without material alteration of the efficiency of the traction equipment, to the same extent as with the two other motor systems,

where this is possible owing to the series characteristic, the series parallel control, or the transformer regulation. Only in this case is the second assumption of this calculation satisfied, namely, that the ratio of maximum to mean load is not greater with three-phase current than with the other systems. Otherwise three-phase current appears still less satisfactory as regards storage.

When water-power is used, we can also, instead of using special storage stations, consider the question of suiting the power stations directly to the total fluctuations in the loads. If the whole fluctuations are taken up by the power station, this certainly necessitates correspondingly great increases in the power of the machines, and considerable increase in the section of the primary mains. It is true that taking into consideration the very large increase in the cost of operation which results if storage is used in the different parts of the distributing system (as shown in our investigations above), it is necessary to examine whether these fluctuations could not, on the other hand, be more economically dealt with direct by the power station, at least in those cases where high pressure and local conditions at the power station make the storage of water possible. A similar comparison was made under the same general assumptions as given above for water storage, between an installation taking four times the mean output as a maximum from one power station, at which a head of water of 200 metres (656 feet) was assumed, and an installation with a power station with the same head, but equipped for only the mean output and with balancing storage batteries at the points of consumption, at the different distances of 0, 50, 100 and 150 kilometres (0, 31, 62 and 93 miles). The calculation assumed in one instance the transformation of current, and in the other no such transformation, all projects being for a single-phase current supply with 15,000 volts on the contact line.

The calculations proved, in all the various cases assumed, that it was far more economical to have the fluctuations dealt with by the power station. The total yearly expenditure for attendance, maintenance, interest and amortization of power station, and balancing storage installations (if any), compared for the delivery of the same amount of energy at the contact wires, is given in the following table:

	System with fluctuations taken up by	
	power station.	balancing batteries in distributing system.
In the following cases:		
No long-distance transmission necessary	100	182
Transmission, without transformation, to a distance of 50 kilometres	100	142
Transmission, without transformation, to a distance of 100 kilometres	100	132
Transmission, without transformation, to a distance of 150 kilometres	100	124
Transmission, with transformation at the supply point, to a distance of 50 kilometres	100	180
Transmission, with transformation at the supply point, to a distance of 100 kilometres	100	144
Transmission, with transformation at the supply point, to a distance of 150 kilometres	100	134

Although these figures depend very largely on the conditions assumed for water-power stations, nevertheless the result is so marked, that it will apply to most cases. In those cases of high-pressure water-power stations where it is possible to deal with the fluctuations of power-demand directly in the power station, instead of requiring special balancing storage plants at the places of consumption, the former procedure is by far the more economical.

This result indicates that that system will be the more economical, which of itself results in smaller fluctuations in the maximum output. In a country where heavy gradients exist, these cause the greatest fluctuations in the load. These are naturally smaller when motors with a series characteristic are used; with three-phase induction motors, a similar limitation of these fluctuations at least presupposes cascade coupling which with large locomotives can be easily accomplished, but which with rail-motor-car traffic undoubtedly causes difficulties. For us it is therefore an advantage, that is to say taking the economical use of water-powers into consideration, to use motor systems with series characteristic, and in particular the single-phase system, as against the three-phase system.

Recovery of energy. — Theoretically one can allow for the energy of inertia recovered by using the motors as brakes, and for the work done by gravity when running downhill. When running uphill, properly-dimensioned motors will in general suffice for recovering most of the energy last mentioned, because not only the energy of inertia, but also the work done by gravity, are not less than that required for running uphill. The energy of the moving train, which has to be taken up by the brakes, is, owing to the rolling resistance, less than that required for driving the train uphill, and the speeds are as a rule not materially different. On the other hand, the recovery of energy by using the motors as a brake generally fails in practice, because these, if they are to act as generators, must be of greater size than if they are to act as motors.

In practice it is necessary that the braking retardations should be greater than the starting accelerations, so that the running time may not become excessive. In fact, all calculations show that the use of the motors as a brake contributes so little energy relatively to the total work, that no importance can be attached to their utilization.

The recovery of energy when trains run downhill is not possible with all electrical systems, or if so, in several instances only with complications. It would at first sight seem, particularly in a hilly country like Switzerland, where heavy up gradients and down gradients are so often encountered, that this recovery would be of great importance. The recovery necessitates the motors working as generators, and for this, with all systems, the electromotive force of the motors has to be raised above the voltage of the contact line. Disregarding arrangements previously referred to, with supplementary generators, separate excitation and the like, as being too complicated for practical purposes, the direct-current series-wound motor is unable to work as a generator. The direct-current shunt-wound motor, however, will as a rule not be used for

the work in question, for other well-known reasons. The three-phase induction motor, on the other hand, is available without further consideration, and the single-phase motor with the addition of voltage increase by means of a train transformer.

The system of recovering energy is very rarely adopted, except in the case of mountain railways, where on very steep gradients the work of gravity much exceeds the work of friction, and where the uniformity of the gradients much simplifies matters (Barmerberg Railway, 185 per mil, direct-current shunt; Filder Railway, near Stuttgart, 172 per mil, direct-current shunt; Gornergrat Railway, 200 per mil, three-phase induction motors; Engelberg Railway, steep section, 250 per mil, three-phase induction motors); in Switzerland, besides the mountain railways named, it is only adopted on the Burgdorf-Thun line (three-phase), and in Italy on the Valtelina line. Measurements have been made in the two latter cases with the following results :

A complete round trip over the whole line of the Burgdorf-Thun Railway made on 3 August, 1908, with a rail motor car, showed :

The complete round required a supply of.	3,102·5	watt-hours per ton	(3,152·3 watt-hours per English ton).
The car gave back	630·4	— —	(640·5 — —).

Which corresponds to a recovery on down gradients of 20·3 per cent.

Similarly a round trip with locomotive No. 2 between Kondolfingen and Burgdorf showed that :

The complete round required a supply of.	1,950	watt-hours per ton	(1,981·3 watt-hours per English ton).
The locomotive gave back. .	483	— —	(490·8 — — .

Corresponding to a recovery on down gradients of 25 per cent.

As compared with the energy theoretically recoverable at the wheel periphery (a probable value for the rolling friction being assumed in the calculation), these investigations show an efficiency of recovery (ratio of electrical energy recovered to work of gravity on the vehicle) of about 63 per cent for the rail motor car and 69 per cent for the locomotive.

For the Valtelina Railway we found (when using the figures given by the State Commission) :

On a down gradient of	12·4	14·9	20 per mil.
With a speed of	62·5	62·5	33 kilometres per hour.
	[(38·8)	(38·8)	(20·5 miles per hour)].
As recoverable at the axles . . .	17·5	22·6	45·5 watt-hours per ton-kilometre.
	[(28·6)	(37)	(74·4 watt-hours per English ton-mile)].
Assuming the most probable value for the rolling resistance, this corresponds to an efficiency of recovery, of the vehicles, of . .	0·66	0·63	0·67 per mil.

These results refer to comparatively steep gradients, of from 12·4 to 25 per mil. On easier gradients, owing to the smaller load, the efficiency of recovery of the motors and vehicles will be materially less; we cannot therefore assume it to be greater than 50 per cent on gradients of 15 per mil, or than about 65 per cent on steeper gradients.

If we consider only railways with heavy gradients, possibly 20 to 25 per cent of the energy supplied to the trains may be saved by recovery on the down gradients; the average conditions of our Swiss Railways will not be so favourable for recovery. Our table of the specific energy demand on the Burgdorf-Thun Railway shows, however, that the saving of energy at the power station, even with the aforesaid favourable figures, only amounts to about 4 to 5 per cent when recovery is adopted, as compared with its absence; this is chiefly due to the preponderating influence of the constant losses in the static transformers.

We give this result here again in another form :

On 6 July 1906, the Kander power station supplied for the working . .	4,947	kilowatt-hours,
Kander energy plus that recovered	5,497	—
Theoretically required at axles.	2,050	—

or consequently 41·5 per cent of the Kander energy without recovery and 37·4 per cent of the Kander energy with recovery.

Consequently, with the average conditions of the Swiss railways we cannot even reckon on 4 per cent total gain by energy recovered, even if we use three-phase current.

This advantage of three-phase current as compared with direct current is consequently quite negligible. With single-phase current, the possibility of recovery is by no means eliminated, although it has not yet been practically tried and is attended with complications; the gain would appear to be still smaller.

Another factor however comes into play; in the interésts of safe working, the authorities in Switzerland demand that the couplings shall remain properly stretched even when running downhill. As long as this well-considered rule has to be observed, the weight of the train (when locomotives are used) cannot be utilized as a source of power, and recovery is therefore out of the question in these cases.

We are consequently justified in the conclusion : The recovery of energy is as a rule of no material importance in the practical operation of the main railroads in Switzerland; the small advantage which the three-phase system theoretically shows in this respect, cannot as a rule be taken into account in selecting the system. These conclusions obviously do not affect special cases, in which this recovery might be very advantageous.

Reliability of operation and strength of the contact line.

Leaving for the moment out of consideration that the different contact-line systems vary widely in cost, the fact remains that the reliability of operation of electric traction depends chiefly on the arrangement of the contact line, as this line is that part of the installation which

is easily affected in many ways, and as failures in the distribution can produce disturbances in the service over a greater area, than, for example, failures in individual motor vehicles.

The third rail, because of its solid construction, has many advocates, especially among railway engineers. It has several decided advantages : great mechanical strength; not affected by wind; easily accessible without hindrance to traffic; less difficulty with tunnels, bridges, and crossings, than an overhead system, especially if the latter uses a high voltage. The disadvantage of frequent and serious disturbance when there is snow and frost, seems according to American experience to be overcome in the newer constructions, at least with enough certainty as far as our climate is concerned. There remain, however, the disadvantages of the expensive maintenance of the timber guards, and the impossibility of ensuring insulation for high voltages; these are really economic disadvantages, which we have already taken into consideration when we took 800 volts as the limit of any applicable system. In addition, there remains the increased danger to the railway staff and to passengers, and consequently the line service and the maintenance become more difficult, especially at stations.

In the case of an overhead line, the latter disadvantages disappear, but, on the other hand, the traffic is hampered during maintenance and repair of the overhead line, and the maintenance in the tunnels is more difficult. Another objection raised against the overhead system is that it is less safe mechanically, particularly as regards the action of temperature and of wind. The scepticism as to the reliability of an overhead-line service is still a strong reason for the aversion to electric operation, particularly among railway engineers. The influence due to atmospheric electricity, for instance, certainly exists. But in this respect, as well as in that of the safety of overhead lines mechanically, so many and excellent improvements have been made that it may well be said, taking these into consideration, that a very high degree of safety has now been attained by their means. We will omit further details about this point, as the modern overhead constructions are thoroughly dealt with in other reports on the subject of the constructions in use. The results obtained on the Burgdorf-Thun, the Engelberg, the Simplon and the Seebach-Wettingen railways prove that failures of the overhead construction can, in fact, be reduced to a very small amount. If we also consider the possibility of ensuring better insulation, which makes it possible to use those high voltages, which are so much more economical, in the overhead construction, one comes to the conclusion, that systems which make overhead construction necessary, that is high voltage systems, are not thereby at any material disadvantage as compared with low-voltage systems which can work with a third rail. On the other hand, even with railways with two-wire overhead lines in which the difficulties resulting from the two-wire system have been overcome to a certain extent in those recently constructed, there can be no doubt that a single-wire overhead construction — irrespective of the possible higher voltages — can be made stronger and more reliable, and is liable to fewer failures, than a two-wire system

with its multiplicity of wires at the switches, and the many insulated joints in the contact line necessitated thereby.

From the standpoint of reliability, there is no doubt that a system for which a single-wire overhead line suffices, is in this respect to be preferred to one with which a two-wire overhead line is required; that is to say, that single-phase current is to be preferred to three-phase current. On the other hand, this need of an overhead line certainly is no disadvantage of these systems as compared with the low-voltage direct-current system which makes the use of the third rail possible.

The influence of the power lines on the telegraph and telephone lines.

This point was made the subject of exhaustive investigation by some of the electric undertakings in our country, and was one of great concern to our state telephone and telegraph authorities and to the railway signalling authorities. The three possible kinds of disturbing influences manifest themselves in something like the following manner :

The voltages above earth, produced in the telegraph and telephone lines by the static induction of the power lines to which they are parallel, are proportional to the voltages of the inducing current; the resulting charging currents are in addition proportional to the inducing periodicity; on the other hand, they are independent of the quantity of the power currents causing induction and therefore are present to practicaliy the same extent whenever any trains are running. The protection against physiological effects of the charging of the telegraph and telephone apparatus is easily effected by proper insulation, by the insertion of intermediate apparatus in the telegraph and telephone circuits and such like. By adopting insulated returns for these circuits, and by crossing them, as well as by using discharging coils, the effects of the charging currents can be materially decreased. In practice, however, the induced circuit is never perfectly insulated, but has varying resistances and capacities distributed irregularly over its length; the charging current accordingly flows irregularly over the whole length of the telegraph or telephone circuit; then the differences in the static charging current, which cannot be determined and which flow along the line itself, exercise a disturbing influence on the telegraph or telephone apparatus in the circuit. These currents are diminished if care is taken to distribute the insulation resistance, self-induction and capacity of the telegraph or telephone line affected, as uniformly as possible over its whole length. The amount of the induced static voltage must theoretically decrease with decreasing insulation resistance of the induced circuit from earth. This generally involves, as has been established by measurements on different railways, considerable decrease of the charging voltage as compared with the theoretical charging voltage when the insulation is perfect. Moreover, the charging voltage decreases when the capacity of the induced circuit increases; as for instance, other conditions being the same, when a telegraph or telephone line running parallel with a railway for a certain distance, then has a continuation extending away from the railway. This case occurs very fre-

quently, for instance on most interurban telephone lines, and is very advantageous as regards the reduction of the effect in question. The increase of the charging current with the periodicity of the inducing voltage, already mentioned, is also of importance. High periodicities are of particular importance; in practice, those of the harmonics of the alternating current used must be taken into consideration, just as are the disturbances arising from dynamic induction by the power currents acting on parallel telegraph and telephone lines. The induction currents flowing in the telegraph and telephone lines, and consequently to the telegraph and telephone apparatus, can materially disturb the working of these apparatus. These currents are proportional to the quantity and periodicity of the inducing current. The changes in the effective value of the power current (which cause induction), as brought about by the working, cannot produce appreciable dynamic induction, as they take place too slowly. The usual periodicities of 15 to 50 per second of the single-phase and three-phase currents do not as a rule produce any current in the telegraph and telephone lines which would disturb their working, even in the case of that most sensitive instrument, the telephone. The harmonics of higher periodicities, particularly those between 500 and 1,500 per second, which are within the limits of the sentiveness of the telephone, cause, on the other hand, buzzing, which may make speaking quite impossible. The simplest remedy for this disturbance consists in arranging the telegraph or telephone lines in close loops, in order to reduce the induction coefficient, as nearly as possible, to zero. Experience however shows that it is generally indispensable also to eliminate the harmonics of the current causing induction.

Finally, we have to consider the stray currents, currents which are really part of the power current itself and escape owing to the imperfect insulation of the overhead line or to excessive and irregular resistance in the rails. The remedy for this, the discontinuance of the use of earth returns, should be applied to the telegraph and telephone circuits, for economical and technical reasons make it impossible for the railway to give up the use of the rails for conducting purposes. With reference to this third class of disturbances, all the three systems of current are practically equal. The greater quantity of the rail currents with the lower voltages balances the greater ease with which leakages take place with the high-voltage contact line.

The comparison of the two other disturbances in the case of the three different systems of current supply shows, on the other hand, the following :

The direct current can cause no appreciable static charges, as this effect only occurs with switching on and off, and is much too small because of the low voltage employed. The results obtained on direct current railways confirm this. Inductive effects occur through harmonics, which may be due to the construction of motors with armature slots or to the use of a commutator. The periodicities concerned would be great enough to influence the telephone; nevertheless, the amplitude of these oscillations is generally small, so that in most cases the telephone service is not materially affected, nor is there any appreciable action on the telegraph lines.

With the high-voltage three-phase current and single-phase current systems, disturbances in the telegraph and telephone lines are caused in the first place by static charges. For instance, measurements which have been made on the sections of telephone line running parallel to the Seebach-Affoltern section of the Seebach-Wettingen experimental railway have shown :

a) Instead of 800 to 1,100 volts, the calculated theoretical value for perfect insulation : 100 to 300 volts charge voltage under the existing conditions of insulation ;

b) Instead of 1,700 to 2,400 volts, the calculated theoretical value for perfect insulation : 800 to 1,200 volts charge voltage under the existing conditions of insulation.

Measurements also were made during the switching on of all the extensive interurban lines (including the whole equipment of the terminus stations), of which the above sections first measured formed part ; they have shown :

In case *a* still 0·70 volt charge. (The atmospheric conditions were unfortunately not the same in both cases.)

The Burgdorf-Thun Railway (700-volt three-phase current with two-wire overhead conductors possesses its own telephone line along the track, for which the calculation showed a maximum induced static voltage of 85 ; the measurements made at different times showed 50, 80 and 108 volts.

Under similar conditions, on the Stanstad-Engelberg Railway, a static charge of 50 volts was measured on the telephone loop during dry weather ; on the telephone line of the cable railway Biel-Läubrigen, which runs parallel to the power line which carries the three-phase 2,000-volt current, the measurements showed 20 to 30 volts during rainy weather, and 100 to 110 volts during dry weather.

These static charges are of themselves physiologically generally harmless, for the capacities are small ; if touched by a person, the reduction in the resistance to earth at once causes a considerable drop in the voltage. Practice confirms this on the Burgdorf-Thun Railway and the Engelberg Railway, where contact with the apparatus, although causing slight shocks, has proved to be quite free from danger. According to the unanimous opinion of several of our electric-railway undertakings, any work on the telegraph and telephone lines of the railway is always carried out without disadvantage or danger while the ordinary train service is being operated. Where greater voltages are used, increased safety can be obtained for the staff by providing insulated standing-places or by insulating the telegraph and telephone installations. Danger from these charges as well as disturbances caused by static charging currents, were also successfully eliminated in the Swiss undertakings and experiments by means of the Ericsson discharging coils.

Those charging currents which occur owing to the imperfect insulation of the telegraph and telephone lines, which always exists in practice, increase with the periodicity of the traction current, and have generally proved those most difficult to deal with. Those charging currents which result from the main oscillations having periodicities of 15 to 50 per second, are generally not liable to disturb the block-signalling apparatus of

the railways, as these respond only to lower periodicities; oscillations with 50 periods also do not, for physiological reasons, appreciably affect the telephone, consequently this is also not affected by the harmonic oscillations, of the 3rd and 5th order, of a 15-period current. On the other hand, disturbances occur with telephones and telegraphs, and are generally difficult to overcome, when more rapid harmonic oscillations of considerable amplitude exist. Consequently it proved necessary in practice to use systems which have the voltage and current curves as free as possible from harmonics and irregularities, with a view to preventing disturbances both from charging currents and from dynamic induction. With both three-phase and single-phase current, it is therefore in the first place necessary to use generators which give, as nearly as possible, a true sine curve. That is equally possible in both cases. With the motors, the slots as well as the commutators cause harmonics. With three-phase motors the former can be closed up, and no commutator exists, so that the condition is more easily satisfied in this case than in that of single-phase motors. The operation of the Seebach-Wettingen section by means of single-phase motors with laminated poles, which will be more fully described further on, has given very interesting results and proved that these harmonics can be satisfactorily eliminated in the case of these single-phase motors also, by suitable design of the slotted armature. Although the single-phase motor built with laminated poles is theoretically somewhat inferior to the three-phase motor in this respect, and the latter in turn inferior to the direct-current motor, existing equipments show that these differences can be made negligible.

The means for reducing the influence of the dynamic induction and the static charging currents in the telegraph and telephone lines are equally serviceable in the case of all the systems, but according to the above are more necessary in the case of single-phase and three-phase current than in that of direct current. They are well known : relaying the telegraph and telephone lines in cables, which generally however is not practicable owing to reasons of economy; relaying at a greater distance from the power lines, which likewise is only practicable in some cases; and then particularly : avoidance of single circuit with use of earth return, and replacement by loops arranged as symmetrically as possible to the inducing power line (crossing at equal distances), besides a distribution of the insulation resistances, self-inductions and capacities as uniformly as possible over the whole length of the telephone or telegraph circuit. These measures are most difficult to carry out when the line must be made up of bare wires and of cables, that is to say when it has a very unequal distribution of capacity.

The following examples serve to show to what extent the telegraph and telephone lines are affected in cases in practice, and how this can be obviated :

Stray currents produced disturbances at different places, in the block-signalling apparatus of the Swiss Federal Railway, such as armatures remaining stuck on; such cases occurred both with direct and with alternating current. They were obviated in every case by the use of metal returns for the block-system telegraph and

telephone lines; disturbances in the original single-wire telephone service of the Burgdorf-Thun Railway were similarly stopped by adding a return wire.

Single-phase railway, Seebach-Wettingen : on the single-wire telegraph line of the Zurich-Seebach-Wettingen line of the Federal Railway, the telegraphing became impossible, whenever the power line was alive. An undisturbed service was again made possible by introducing a double line up to the then-existing end of the power line (Affoltern); the continuation remained a single-wire line, however, and the double line was only crossed on the sections parallel to the railway. When the traction experiments were subsequently extended from Affoltern to Regensdorf, the telegraph and telephone lines running alongside were continued to the latter place as loops, but not crossed; they afforded a very good telephone and telegraph service. A completely-closed unearthed loop, Zurich-Regensdorf, did not show the least disturbing influence. When the power line was subsequently extended from Regensdorf to Wettingen, the still-existing single-wire telegraph circuit showed a charge current which was 3·3 times greater with 50-period operation than with 15-period operation; and this made the telegraph armature swing. The disturbing influence of the charge current disappeared after using a non-earthed bare-wire loop over the whole length along the railway. When, on the other hand, a cable generally used as well, 4·5 kilometres (2·8 miles) long, between Zurich and Oerlikon, was included in this loop, then the static charging currents which disturbed the telegraph service could only be reduced by means of discharging coils to an extent which again made telegraphing possible. The static charging voltages came into existence, because the two conducting wires were not charged to exactly the same potential; and they amounted, without discharge coils, to 280 volts with the cable switched in, and to 580 volts without it; with discharge coils they still amounted to from 70 to 80 volts. The telegraph service could be resumed with the simple arrangement of a double wire, accompanied by the arrangement of the ink-writers in parallel, instead of the previously-used series arrangement; by this means, the discharge of the loop was accomplished by simply earthing the middle of the electro-magnets. The block apparatus showed no disturbances, but were equipped with insulated return circuits when the railway contact-line was lengthened, in order to avoid the influence of earth currents. The bell-signal equipments showed themselves still less sensitive, and did not require an insulated return circuit.

On the telephone circuits, the following was observed : On uncrossed bare-wire loops along the railway, an induced note (not sufficient to hinder the telephone service) was audible when switching the current on to the contact line, but this was not the case with crossed loops. When trains passed, the induction in the experiments with the locomotive motors with commutators and laminated poles used since 1906, caused in an uncrossed bare-wire loop, a shrill, loud whistling, which greatly disturbed the service. With a bare-wire loop crossed at every fourth pole, the whistling was still aud-

ible, though less disturbing; in a shorter loop still crossing at every pole, disturbing sounds could hardly be heard. With longer circuits, however, it appeared that the telephone disturbances could not be reduced to the desired amount merely by devices applied to the telephone lines. The Oerlikon Works first of all ascertained that the number of vibrations of this whistling sound synchronized with that which resulted from the number of slots and revolutions of the motors, and that the amplitude of these harmonics amounted to up to 20 per cent of the amplitude of the original wave. These vibrations proved to be independent or only slightly dependent on the commutation in the commutator. Motors were then built which had armatures with closed slots and which in addition were spirally twisted one slot-division. When these motors were used, the influences mentioned then became so reduced that the telephone worked satisfactorily.

The telegraph and bell signals of the Burgdorf-Thun Railway have in no way been disturbed since the joint insulated return circuit was put in, although the lines of the loop are not crossed.

The example of the telephone circuit of this railway has already been mentioned above. We will here merely mention that substantially analogous results were obtained in experiments made on the Swedish State Railway.

As a result we believe we can draw the following conclusion :

The mitigation of the disturbing influence of railway power lines on telegraph and telephone lines is somewhat more difficult with the alternating-current systems than with the direct-current system. Under all circumstances and with all systems it is necessary, if only on account of the stray currents, to adopt loops and to abolish the earth return for all those low-voltage circuits (telephone, telegraph and signalling systems) which must remain alongside the railway, and can not be removed to a greater distance from it. With the telephone circuits, a crossing of the lines, more or less frequent according to the circumstances, is necessary; with less sensitive apparatus (block signals), a common return for a number of circuits suffices in most cases. In order to reduce the static influence, attention should be paid to having the capacity distributed as uniformly as possible (for example, avoiding the junction of cable with bare-wire lines). With the alternating-current systems, the production of harmonics must be rigidly guarded against, and this is somewhat more difficult with single-phase motors than with three-phase induction motors. No important difference, from the point of view of influence on the telegraph and telephone lines, exists between the different current systems; in any case, three-phase current and single-phase current are practically equal in effect, and the precautions mentioned for the telegraph and telephone installations must also to be taken into consideration when direct-current traction is used. They must be allowed for when making estimates of the cost of electric traction; but they also make it possible to have low voltage and high-voltage lines operated in the immediate proximity of each other without disturbance.

A review of the advantages and disadvantages of the three possible traction

systems with reference to all the conditions discussed, leads us, if we consider the relative importance of the individual points, directly to the conclusion, in so far as can be foreseen in this way, that the single-phase system offers the best technical advantages. In this connection we have, until now, left one question undecided : What periodicity is it most advantageous to use? We found that this question could not be decided on purely theoretical grounds, at least not sufficiently exactly : our considerations up to this point have however been confined to the technical properties of the systems. As they show that all these available systems can give technically satisfactory solutions, the question of the cost of operation must now be taken into consideration. In this comparison, we still include the three-phase system, as we found this to present many technical advantages for the operation of standard-gauge railways. The question of the periodicity accordingly still remains open as regards this system.

Let us again consider the purely technical conditions from the point of view of periodicity. With the single-phase commutator motors, the maximum torque for starting is limited by the amount of current which can be commutated without sparking when starting; an amount which diminishes with increase of periodicity, so that the ratio of the starting torque to the normal torque, becomes smaller and finally too small, the greater the periodicity. This is in favour of the lowest possible periodicities. A similar effect is produced by low periodicity, for a definite normal torque, by the reduction of weight and the increase of efficiency, and in the case of uncompensated motors, by the fact that a higher power factor can then be obtained. In the case of three-phase current, considerations regarding the suitable design of slow-running motors for locomotives are in favour of low periodicities; in other cases, the periodicity has little influence on the design of motors of this kind.

As regards the transmission, the lowest possible periodicities are likewise favourable, because of the reduction of voltage drop, especially in the rails, and particularly because of smaller losses of energy in the latter.

With the generators and transformers, no great differences exist in the efficiency at the periodicities in question, but, on the other hand, low periodicities require larger dimensions, weights and costs. particularly in the case of the transformers and, to a minor degree, in that of the generators and synchronous motors (at substations). The question of weight also requires consideration, on purely technical grounds, in the case of train transformers, owing to the dead weight which has to be hauled.

The question of having good motors is that which requires most attention in the case of electric traction. So far all experience shows that in the case of single-phase current, the periodicity must not exceed 25 periods per second. In the case of three-phase motors, one can probably go to 50, even in that of slow-running locomotive motors. A lower periodicity would be technically more advantageous in both cases; but the technical advantages to the motors, when the periodicity is reduced to below 20 or 25, are no longer of any great importance,

and as against them there is the higher cost of the transformers and, in some cases, of the generators. When the periodicity is reduced, the price of the rolling stock is lower, while that of the stationary plant is higher. The ultimate decision must be logically based on economical considerations.

The Commission of investigation has accordingly made detailed estimates of the cost of equipments, using prices which were stated, by the various firms concerned to be correct. Such estimates were made for one and the same railway both for single-phase current with 15 and 25 periods, and for three-phase current with 15 and 50 periods; this was done both for the St. Gothard Railway and for district II of the Swiss Federal Railway. In the case of single-phase equipment, the result was that the reduction in cost of the rolling stock for 15 as against 25 periods was greater than the corresponding increase in cost of the transformers, generators, and power-station equipments, so that it would be considerably cheaper to use 15 periods. The result naturally depends upon the density of traffic assumed, because the amount of rolling stock necessary has an influence, as well as the maximum power necessary, and the yearly output of the power stations. The resulting figures (which we will deal with in detail later on) are however such that one can safely assume that a relation of the same kind will exist in the case of all standard-gauge railways, which can show a given traffic density. In the case of three-phase current, the result was that with 50 periods the generators and transformers, as well as the contact line and rolling stock, are materially cheaper than with 15 periods, while the cost of the installation for the distribution of energy at 15 periods becomes but little cheaper. On the whole, the differences in the amounts are small in this case, and can not be decisive; thus a lower periodicity in the case of three-phase current can not on the whole be shown to be a decided advantage.

We do not consider it material that higher periodicities may be more advantageous for the direct supply of lighting current; the tendency in car lighting has so far been that all the car should be equipped with small batteries and with seperate axledriven dynamos, and many of them have by now already been equipped in this way; as regards large stations, special lighting equipment will in any case be provided; and after all lighting is possible even in the case of 15 periods, if suitable incandescent lamps are selected.

Among the general points of view affecting the selection of the periodicity, one which is often mentioned is the possibility of conveniently obtaining a supply of current from existing power stations, which in Switzerland work in most cases with 50 periods, and in some with 40 and 42 periods. We do not attach much importance to this point, seeing that the Federal Railway will build its own special power stations for supplying the traction current; and as these power stations will be independent of other undertakings, they can have any suitable periodicity.

The Commission of investigation therefore came to the conclusion that in the case of single-phase current a periodicity of 15 was to be considered the most advantageous, and to be adopted for further projects. Above all, it will give very

good motors and is economically advantageous. Obviously, this periodicity should be adopted not only for the trunk lines, but also for the branch lines; where the supply of the latter, from existing stations, with current of 40, 42 and 50 periods, has to be taken into consideration, the adoption of a periodicity between 50 : 3 = 16 $^2/_3$ and 40 : 3 = 13 $^1/_3$ will not present any obstacle, as it will not prevent the use of the rolling stock which is equipped for these somewhat different periodicities, on the main railroad system which is equipped for 15 periods.

III. — Comparison of cost.

As regards the comparison of the cost of the different systems which the Congress desired to include in the report on question VIII, we think we can give a valuable contribution by quoting the results of the Swiss Commission of investigation. The Commission of investigation attached, as already mentioned, particular importance to the question of which system was to be adopted, but it also made it possible to solve the question, very important to Switzerland, whether electric traction when using water-power would be cheaper or at least as cheap as steam traction, both as regards the existing traffic and that to be expected in the future.

The projects and estimates for construction and for operation, which we worked out, were modified in several points during the progress of the work, corresponding to the results obtained in the meantime; in particular, it was found that by modifying the first assumptions and improving the time-tables and starting conditions, so as to make them more suitable for electric operation, the latter became possible without reducing the traffic facilities desired, and that at a lower cost. The last and most favourable projects are consequently still being worked upon. However the earlier projects, less favourable from the point of view of electric traction, already gave valuable and decisive results as to the relative cost of the different electric systems, as compared with each other, and as compared with that of steam operation. We will illustrate this by the results obtained in the case of the St. Gothard Railway (now Federal Railway, district V), for which several sets of estimates were worked out, and among them in particular one for a future greater traffic; and this we will next consider.

This project was based on assumptions which specified very high requirements, as regards traffic and loads, as compared with those now in existence. The following are the assumptions made :

Running speeds to be used, in kilometres per hour.

—	On up gradients of					
	0 °/₀₀	5 °/₀₀	10 °/₀₀	15 °/₀₀	20 °/₀₀	26 °/₀₀
Express trains. . . .	90 (75-90)	90 (75-90)	90 (45-65)	75 (45-55)	65 (35-47)	60 (25-35)
Passenger trains . . .	75 (60-75)	75 (60-70)	75 (40-60)	70 (35-50)	65 (30-40)	60 (25-30)
Goods trains	45 (45)	45 (30-45)	45 (20-30)	42 (15-25)	38 (15-25)	36 (15-20)

The figures in brackets are the speeds hitherto obtained with steam traction.

Train loads to be hauled, in tons.

—	Express trains.		Passenger trains.		Goods trains.	
	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
On the sections :						
Luzern-Erstfeld	350	400	200	250	600	700
Erstfeld-Biasca	350	400	200	250	400	600
Biasca-Bellinzona	350	400	200	250	600	700
Bellinzona-Chiasso	350	400	200	250	400	600
Bellinzona-Luino	200	300	150	250	200	700
Bellinzona-Locarno	...	...	150	250	200	250
Zug-Goldau	150	200	150	250	600	700

Number and time distribution of trains. — Express trains about as at present, but duplicating all midday trains; ordinary passenger trains at the most regular intervals possible, according to the requirements of the district, so that they follow each other every 1 to 1 $^1/_2$ hours in both directions. Goods and optional trains almost as with steam traction, but for the optional trains a great number as maximum.

Total traffic. — The total traffic with this time-table amounted per day to 17,665 train-kilometres (10,977 train-miles) and to 6,333,000 ton-kilometres (3,873,000 English ton-miles) (gross) in round figures; the corresponding means for the year 1906 were 10,900 and 3,770,000 respectively (6,773 train-miles and 2,306,000 English ton-miles).

These figures were then used for two different cases : in the first (A) the calculated day was taken as maximum day, in the second (B) it was taken as the average day of the year, and, in accordance with a determination made in previous years, the maximum day was assumed to have 54 per cent more traffic.

Case A, therefore, shows a gross traffic of 1,710,000,000 ton-kilometres (1,045,782,000 English ton-miles) per year (locomotives included) or an increase of 25 per cent as compared with the steam traffic in 1906.

Case B shows a gross traffic of 2,300,000,000 ton-kilom. (1,407,000,000 English ton-miles) per year (locomotives included) or an increase of 69 per cent as compared with the steam traffic in 1906.

Excluding locomotives, the following figures, which give a better basis for comparison in the case of electric traction, represent the gross traffic :

Case A, 1,300,000,000 ton-kilometres (795 millions English ton-miles) per year or an increase of 36 per cent as compared with the steam traffic of 1906;

Case B, 1,760,000,000 ton-kilometres (1,076,000,000 English ton-miles) per

year or an increase of 84 per cent as compared with the steam traffic of 1906.

In making the estimates for the conductor lines for the distribution of energy, it was assumed that on sections having gradients of up to and including 10 per mil, the trains would as a maximum follow each other, in both directions, at block or station intervals, so that every block-section would contain one train, whether the track section was single or double track; on steeper gradients, it was assumed that there would be only one train per track section. The two sets of express trains following each other were assumed to be in the most unfavourable positions. The division of the track sections and their relation to the feeding stations and lines were adapted to the existing railway stations and junctions. As principal feeding points, we took Goldau and Amsteg in the north, and Lavorgo, Giubiasco and Melide in the south; they were fed from the power stations by means of 45,000-volt power mains, and balancing batteries were installed where it was thought that they would be necessary.

As power stations, the following were assumed to be available in the future for the railway; one station at Amsteg, to be supplemented later on if necessary by one at Göschenen for the north side; a similar one at Lavorgo, to be assisted in case of increased traffic by a similar one at Ambri-Piotta, using the Ritom lake. In all cases, they also feed a section of the contact line direct.

The capacity of the power station units (turbines, generators and transformers) was so chosen that a number of units could be selected to run at normal load both under the condition of the heaviest-load period and that of the lightest-load period of the day. Even when there is storage at the feeding points, the water-power installations would not suffice unless a certain amount of water storage was provided, such as is possible in these cases; and this was assumed to be the case.

In determining the cost of the installations, the unit prices of the machines, apparatus and rolling stock were each carefully fixed, on the basis of definite projects, with the co-operation of the manufacturers in Switzerland; in the case of accumulator batteries, very low prices are assumed, which according to the statement made by an accumulator manufacturer, are probable for large batteries in the future. The price of copper assumed was the market price at that time; now it would be considerably cheaper.

Plans and estimates were then made of several distribution projects, so as to eliminate, as in the former cases, uneconomical systems. These projects were:

Single-phase current with 15 periods and with 25 periods, in one case for each periodicity without balancing batteries (the whole of the fluctuations being absorbed at the power station); in a second case, for each periodicity with balancing batteries at three and also at two of the feeding points before mentioned without using transformers; and in a third case, for each periodicity, with balancing batteries and transformation from three-phase current, at three and also at two of the feeding points;

Three-phase current with 5,000 volts at the contact line, with 15 periods and with 50 periods, in one case for each periodicity without balancing batteries, and in

another case, for each periodicity with balancing batteries but without transformers; and with 15 periods only with transformers at two of the feeding points;

Direct current at 3,000 volts in the contact line, in one case with balancing batteries and with transformation from three-phase current at all the feeding points, and in another case also with this transformation but without balancing batteries.

The annual cost of operation was then determined for these various cases, in the first place only as far as the distribution proper was concerned. The percentage rates for interest, sinking fund, and renewals, as well as the amounts for upkeep and repairs were assumed to be the same as with steam operation, as far as this was practicable; in the other cases, results obtained by electric undertakings were taken as basis. The pay of employees was assumed to be the same as at present.

The second and third columns of the following table D contain, respectively the total outlay and the total yearly expenditure for the distribution installations by themselves, that is to say, the substations and the transmission lines included with them.

It appears, as was to be expected from the great first cost of the batteries, and the expense of their upkeep, that not only the first cost, but also the annual expenses of the distribution installation in the case of every current system arranged with balancing batteries at the chief feeding points, prove to be much greater than when the fluctuations are dealt with at the power house. Further, in the first case, owing to the loss in the balancing batteries, more energy must be delivered by the power station. On the other hand, it is obvious that in the second case the power station must be built for an increased maximum output and will therefore cost considerably more to instal; in addition, as was previously shown in detail, a greater quantity of water is required to supply a kilowatt-hour from the power station, than when balancing batteries are used at the feeding points, because as many turbines and generators must be always kept running as are necessary for the maximum load to be expected, so that a large loss results, particularly when the turbines are running at no-load. Both factors increase the cost per kilowatt-hour at the power station. One can, however, already recognize from the great difference between the yearly costs of energy distribution, with and without balancing batteries, as shown by the third column, that the above-mentioned difference of cost per kilowatt-hour at the power station would have to be excessively large in order to counterbalance the increased cost of the distribution. But the general investigation of installations with balancing batteries, which was mentioned above, showed that when the maximum power required was directly supplied by the power station, the cost of the energy itself, for the two reasons given, would exceed by about 20 per cent that required of a correspondingly smaller power house when the power is supplied to a network with balancing-battery installations at the feeding points. This increase of cost will of course vary considerably according to the conditions affecting the water-power, and may in some instances differ considerably from the figure given; the further figures of the table show, however,

Table D.

Capital outlay and yearly expenditure on distribution, amount of energy and expenditu

SYSTEM OF WORKING.	Capital outlay on distribution (substations and electric mains	Expenditure on substations and electric mains per year.	Energy demand at power station, per year, in traffic case	
			A	B
1	2	3	4	5
	Francs.	Francs.	Millions of kilowatt-hours.	
Single-phase current, 15,000 volts, 15 periods :				
a) without storage	2,632,800	317,830	85·6	114·2
b) with storage, without transformation at Goldau, Giubiasco, Melide	10,275,600	1,487,830	98·5	133·0
c) with storage, without transformation at Goldau and Giubiasco	10,534,700	1,504,220	65·5	88·5
d) with storage and transformation at Goldau, Giubiasco, Melide	11,508,800	1,634,310	108·2	144·8
e) with storage and transformation at Goldau and Giubiasco	11,740,500	1,643,960	70·2	94·9
Single-phase current, 15,000 volts, 25 periods :				
a) without storage	2,411,000	290,370	85·6	114·2
b) with storage, without transformation at Goldau, Giubiasco, Melide	10,011,600	1,451,660	98·5	133·0
c) with storage, without transformation at Goldau and Giubiasco	10,219,200	1,461,910	65·5	88·5
d) with storage and transformation at Goldau, Giubiasco, Melide	11,282,800	1,606,860	108·2	144·8
e) with storage and transformation at Goldau and Giubiasco	11,444,700	1,607,840	70·2	94·9
Three-phase current, 5,000 volts, 15 periods :				
a) without storage	6,661,100	809,730	91·5	123·6
b) with storage at Goldau and Giubiasco	14,918,000	2,089,650	109 2	147·5
c) with storage and transformation at Goldau and Giubiasco	16,126,600	2,239,080	114·3	154·5
Three-phase current, 5,000 volts, 50 periods :				
a) without storage	6,968,800	867,770	91·5	123·6
b) with storage at Goldau and Giubiasco	14,968,400	2,118,030	110·1	148·8
Direct current, 3,000 volts :				
a) with transformation and storage at all substations	25,081,000	3,660,340	100·9	136·5
b) with transformation but without storage	...	...	...	...

N. B. — The bracketed figures for the expenditure on energy and the figures for the total cost of the service are those obtai

Table D.

energy for operating the St. Gothard Railway in the two proposed cases.

Expenditure on energy at power station per year, in traffic case				Expenditure on energy at contact line, per year, in traffic case			
A		B		A		B	
at a price, in centimes, per kilowatt-hour of				at	at	at	at
2 and 2·4.	3 and 3·6	2 and 2·4.	3 and 3·6.	2 centimes.	3 centimes.	2 centimes.	3 centimes.
6	7	8	9	10	11	12	13
Thousands of francs.				Thousands of francs.			
2,054 (2,172)	3,082	2,741 (2,436)	4,111	2,372 (2,490)	3,399	3,059 (2,754)	4,429
1,970	2,955	2,660	3,990	3,458	4,443	4,148	5,478
2,022	3,033	2,732	4,098	3,526	4,537	4,236	5,602
2,146	3,219	2,896	4,344	3,780	4,853	4,530	5,978
2,172	3,258	2,934	4,401	3,816	4,902	4,578	6,045
2,054 (2,110)	3,082	2,741 (2,370)	4,111	2,345 (2,409)	3,372	3,031 (2,668)	4,402
1,970	2,955	2,660	3,990	3,422	4,407	4,112	5,442
2,022	3,033	2,732	4,098	3,484	4,495	4,194	5,560
2,146	3,219	2,896	4,344	3,753	4,826	4,503	5,951
2,172	3,258	2,934	4,401	3,780	4,866	4,613	6,009
2,196 (2,050)	3,294	2,966·4 (2,298)	4,449·6	3,006 (2,860)	4,104	3,776 (3,108)	5,259
2,184	3,276	2,950	4,425	4,274	5,366	5,040	6,515
2,286	3,429	3,090	4,605	4,525	5,668	5,329	6,934
2,196 (1,989)	3,294	2,966·4 (2,229)	4,449·6	3,064 (2,857)	4,162	3,834 (3,097)	5,317
2,202	3,303	2,976	4,464	4,320	5,421	5,094	6,582
2,018	3,027	2,630	4,095	5,678	6,682	6,290	7,755
...	...	...	...	4,382	5,693	5,296	7,074

n special calculations of costs at certain existing water-power installations at the St. Gothard.

that qualitatively the result will remain the same, even when this increase of cost is much greater. For the purposes of this general comparison, the use of such an average increase of cost was therefore preferable to calculating the result in the case of a special power station. Even the absolute cost per unit of energy at the power station was, in the first place, assumed at this stage of the comparison of cost; two different values were taken, and it was assumed that the actual cost probably would lie between them. These two values were 2 and 3 centimes (0·19 and 0·29 *d.*) per kilowatt-hour at the power house, when the energy was supplied to a network which included balancing-battery installations; as stated above they were assumed to be 20 per cent higher, namely 2·4 and 3·6 centimes (0·23 and 0·35 *d.*) respectively, when there were no such balancing batteries. (The separate estimates subsequently made for a power station showed that the cost of power was in this case rather less.)

Further calculation then gave the figures for the energy required (columns 4 and 5) and for its total cost per annum, at the power station (columns 6 to 9). The figures are given both for light traffic (case A described above) and for heavy traffic (case B). Adding to this the expenditure per annum for the distribution of power (given in column 3) we obtain the figures (given in columns 10 to 13) for the total expenditure on energy delivered at the contact line and required for the railway in question; this total expenditure includes the whole expense of generation and distribution of current. The comparison of these last figures gives the clearly-defined result, that with every system of current supply the total expenditure for energy required at the contact line is considerably greater in those cases in which balancing batteries are used at the feeding points. This result would still be obtained if one took rather different figures for the cost of energy at the power station for both in the cases with and without balancing batteries. Consequently when water-power is used, whatever the nature of the current supplied, only those arrangements come into economical consideration in which the load fluctuations are taken up at the power station itself, without the use of balancing batteries in the distributing network. In continuing the investigations, the latter case only was therefore considered.

Our former table D also shows that the direct-current system as compared with the others is obviously at an enormous disadvantage economically. The difference between direct current, on the one hand, and three-phase and single-phase current, on the other (7 to 7 $^{3}/_{4}$ as against 4 $^{1}/_{2}$ to 5 million francs [£280,000 to £310,000 as against £180,000 to £200,000] per year), includes it is true so far only the expenditure for energy supplied at the contact line. It is however easy to see that the further items which still must be added in order to obtain the total expenditure on operation, namely the expenditure on the traffic department proper including interest on the capital outlay; expenditure on renewals and maintenance, on all the traction equipment and its accessories, and on the contact line itself, will not differ much with the three systems. In order, however, to make a complete comparison, we have completed the full calculations for all the three systems.

We would also draw attention to the figures for the differences (determined when discussing the periodicity) in the first cost of the power-distribution installation and in the total annual expenditure on energy at the contact line, according as 15 or 25 periods are selected in the case of single-phase current. In all cases, the expenditure is appreciably lower with 25 periods, while the corresponding differences are so small in the case of three-phase current, with 15 and with 50 periods, that no decisive importance can be attached to them.

For those systems which had proved to be more favourable, the cost of the further equipment, the railway traffic equipment proper, was then worked out. This equipment includes : the contact line, the rolling stock, the car sheds and stores, the telegraph and telephone lines or their modification, and various accessories. The projects under consideration are based upon the following assumptions :

As regards the contact line, the cross-section, everywhere on the main line (including the turn-outs on single-track sections), is assumed to be 100 square millimetres (0·155 square inch) and 50 square millimetres (0·077 square inch) in the case of the sidings at stations. In addition, feeder mains are laid alongside all main lines : these mains make it possible to subdivide the contact line into sections between the stations and also to cut out sections without interrupting the whole system, that is to say, while maintaining the through flow of current. The maximum admissible voltage drop in the contact line (including the feeder mains) was assumed to be 20 per cent of the voltage (kept uniform) at the feeding points in the case of single-phase and of direct current, and 15 per cent in that of three-phase current (in this case the drop is less, as the reduction in the maximum torque comes into consideration); these figures are, however, as a rule not attained with the minimum cross-section used. Without definitely settling on any of the newer systems of insulating and supporting the contact line, the sum allowed for its cost was ample for good and solid work; the supports were to be made of iron exclusively. Any special devices necessary, any alterations in existing track appliances, etc., were made the subject of separate estimates.

The driving equipment assumed was as follows :

A type of express locomotive, a type of goods locomotive and a type of rail motor car. Both the express locomotives and the goods locomotives, can be designed and are assumed to have been designed, so that they could be used to advantage both on down gradients, not exceeding 10 per mil, and on up gradients, not exceeding 26 per mil. The design of these locomotives was based on the following assumptions as to power :

—	Up gradient, in mil.	Load hauled, in tons.	Speed, in kilometres per hour.	Output, in useful horse power.
Express locomotive.	0	320	90 (90)	... 1,400
	5		90 (80)	2,200 (1,800)
	10		75 (70)	2,300 (1,900)
	26		60 (50)	3,800 (2,800)
Goods locomotive.	0	500	45 (45)	... (500)
	5		45 (45)	... (1,000)
	10		45 (45)	1,500 (1,500)
	26	320	35 (35)	1,800 (1,800)
Passenger rail motor cars (two of this power per train).	0	250 (1) (200)	75 (75)	... (400)
	5		75 (70)	... (620)
	10		75 (60)	1,200 (710)
	26	250 (1) (150)	60 (50)	1,800 (890)

(1) Including the rail motor cars themselves.

In finally working out the schemes, these figures were subsequently reduced to those given in the brackets, as this proved admissible and advisable. The weights assumed for the express trains correspond to the maximum drawbar pull on a gradient of 26 per mil; the speeds assumed correspond to the assumptions previously made. Locomotives alone have to be considered for operating the express-train and the goods-train traffic; they will probably also be used for part of the passenger-train traffic, but the greater part of the latter, particularly the local traffic, can be dealt with more profitably by means of rail motor cars, which were assumed to be used as third-class passenger carriages.

The determination of the number of driving units necessary was effected with accuracy; it was based on a definite time-table for the trains and locomotives, allowances being made for the reserves and for stock under repair, which experience proved necessary. In this way, the following were determined to be necessary:

—	Express locomotives.	Goods locomotives.	Passenger rail motor cars.
For regular trains	6	18	13
For periodical trains	4	...	...
For reserves ready for use and for double-heading	2	...	13 (13)
Under repair and not usable	2	18 (15)	6
	14	36 (33)	32 (26)

A small change in the arrangement, subsequently made, showed that the number of vehicles given in brackets, would suffice. The outlay, as has already been stated, was determined, as accurately as possible, with the help of the manufacturers, and was partly based on existing estimates.

The total outlay on driving equipment, excluding the carriage work for the rail motor cars, amounts for the stock assumed, but somewhat reduced, to :

—	Single-phase current of		Three-phase current of	
	15 periods.	25 periods.	15 periods.	50 periods.
	Francs.	Francs.	Francs.	Francs.
For 14 express locomotives	4,312,000	5,174,400	4,312,000	3,920,000
For 33 goods locomotives	5,989,500	7,187,400	5,989,500	5,445,000
For 26 rail motor car equipments	2,246,400	2,620,800	2,620,800	2,246,400
For spare parts, heating appliances and boiler vans	500,000	500,000	500,000	500,000
	300,000	300,000	300,000	300,000
	240,000	240,000	240,000	240,000
	13,587,900	16,022,600	13,962,300	12,651,400

These figures show, as already stated, that the first cost of the total driving equipment is materially less in the case of 15-period single-phase current that in

that of 25-period current, while in the case of three-phase current 50 periods have the advantage, but only to an unimportant extent.

Besides this new driving equipment, which electrification makes necessary, the two cases of increase of traffic assumed (as compared with the present traffic) also make it necessary to increase the number of ordinary trailers, in the case of both passenger carriages and goods wagons. The additions necessary are assumed in case A to be 154 passenger-carriage axles and 1,616 goods-wagon axles, and in case B to be 514 passenger-carriage axles and 3,856 goods-wagon axles; these additions are allowed for in the estimates.

Moreover, separate estimates were made for altering and rebuilding the car and locomotive sheds, in cases where this was necessary, and this expenditure was determined.

A special investigation was then devoted to the cost of altering the telegraph and telephone systems. The following conditions were assumed necessary for the service lines: all telegraph lines to have metal return lines; to provide separate telephone lines with loops which run from block to block without intermediate connections, so that in case of any failure of the block signalling apparatus quick communication is still possible; to provide an insulated return for bell signals; to extend the block system to all the railway lines, putting in metal return lines; to arrange all the signal transmissions so as to have the signals repeated at the stations by means of the actuating current. All the new telegraph and telephone lines are to be carried on poles about 20 metres (66 feet) from the contact line; they are to be crossed at intervals and fitted with discharge coils; the poles for these lines must be put in new. As regards the Federal telegraph system, a new route is to be selected, at some distance from the railway, preferably along the highway, and new telegraph lines are to be put up. The whole scheme, including all these details, works out at a rather high figure, namely 2,500,000 francs (£100,000) for the railway service lines and 1,500,000 francs (£60,000) for the Federal lines, including an allowance for any unforeseen expenditure.

In the above comparison of the different cases, the expenditure on energy delivered at the power station was assumed to lie within certain limits; at this stage of the calculations it became necessary, in order to obtain as close an approximation to the truth as possible, to obtain the assistance of the engineers acquainted with the circumstances, and to study those water-powers which would be available for the St. Gothard scheme, as carefully as was possible without making special surveys. As already mentioned, four power stations are in question: one at Amsteg, one at Göschenen, one below the Ritom lake, and one at Lavorgo. These were assumed to be built for a maximum momentary output of about 37,500, 20,000, 40,000 and 22,500 horse-power respectively; and in the case of the latter, when fully equipped, 67,500 horse-power. For traffic A, the construction of the Göschenen power station can be omitted; it is only assumed to be constructed in the case of traffic B.

According to a preliminary estimate of the necessary maximum output, the power station at Amsteg would, it is true, have been required to provide 7,500 horse-

power more; a later investigation with a better time-table, with at least the same traffic carried, showed, on the other hand, that the maximum loads could be assumed to be lower than those mentioned.

The works were assumed to be equipped with the necessary water storage to provide for the fluctuations in the load. The resulting costs of the installations (in francs) were as follows :

—	POWER STATIONS			
	Amsteg.	Göschenen.	Ritom.	Lavorgo.
For operation with single-phase current, 15 periods .	8,300,000	3,300,000	7,500,000	11,350,000
— — — — 25 — .	8,090,000	3,240,000	7,170,000	11,125,000
— three-phase — 15 - .	7,850,000	3,100,000	6,825,000	10,950,000
— — — — 50 — .	7,625,000	3,000,000	6,490,000	10,750,000

These figures also show the amounts saved in the construction of power stations (referred to above) when 25 periods as against 15 are adopted in the case of single-phase current, and 50 periods as against 15 in the case of three-phase current; the saving in the latter case is insignificant.

These particulars concerning the expenditure on interest, sinking fund, maintenance, supervision and labour make it possible to obtain more accurate estimates of the annual expenditure on energy at the power stations. The following results are obtained :

—	With single-phase current.		With three-phase current.	
	15 periods.	25 periods.	15 periods.	50 periods.
	Francs.	Francs.	Francs.	Francs.
Traffic A	2,172,000	2,110,000	2,050,000	1,989,000
— B	2,436,000	2,370,000	2,298,000	2,229,000

We have inserted these figures in table D in the columns of the corresponding systems in brackets; as may be seen, these differ very little, on the whole, from those limits of the expenditure on energy which previously were merely assumed for the purposes of comparison. The figures inserted in brackets in the next columns of the table for the cost of energy at the contact line are determined from these corrected values.

We next have to determine the expenditure on operation of the train service proper. This includes (according to the system of book-keeping in use on Swiss railways) the following items : pay of chief locomotive engineer and of his office staff, of the locomotive staff and of the

carriage examiners, of the cleaners, lampmen, etc. and also (exclusive of the electric energy required, which is charged for specially) the fuel for the existing steam locomotives, which, it is assumed, would still be used for shunting operations, all lubricating materials, the expenditure for heating and lighting the trains, various supplies for the rolling stock, the expenditure on upkeep and repair of the rolling stock and contact line, and miscellaneous expenses. Naturally in drawing up these estimates, the increased staff and increased working expenses, which would result from the increased traffic, were allowed for. The staff which was assumed was determined jointly with the railway management. The staff for equipping and cleaning the locomotives could be reduced; on the other hand, two men, as in the case of steam, were assumed to be on each locomotive. The expenditure for lubricating material consumed by the electric locomotives and rail motor cars, the electric heating and lighting of the cars, and the upkeep of the electrical details of the locomotives and rail motor cars, could be determined with sufficient certainty from existing electric-traction systems, and ample allowance was made for those items; lubrication and upkeep of the mechanical parts which remained the same as in steam traction were fixed in accordance with the results obtained in that case.

In this way, we have arrived at the following yearly expenditures for the electric-traction service proper exclusive of the expenditure on energy :

	With single-phase current.	With three-phase current.
	Francs.	Francs.
Traffic A.	4,707,200	4,798,800
— B.	5,515,400	5,607,000

Finally, if we add all the items together, we obtain the results given in table E, in which the actual expenditure on steam traction with the present smaller traffic is also given; in this table we have however only considered 15-period single-phase current and 50-period three-phase current, as these are the most favourable systems.

This table leads to the inference, with reference to the two competing systems included in it, that in the case of the smaller traffic, as well as in that of the larger traffic, the three-phase current is about 8 per cent less economical than the single-phase current. Of the assumptions made, one or the other may not be quite correct and many of them depend on the special conditions of the power stations and the railway line. The resulting figures should therefore certainly not be taken as true absolute values, but on the contrary, especially the cost per unit of load carried, should be taken only as comparative figures. If one considers the existing possibilities of changes in the figures taken as bases in the calculations, one can however recognize, that even if great changes are assumed, the difference between the two systems will in all probability always remain on the same side

Table E. — Amount of traffic, capital outlay and total running expenses of the St. Gothard Railway.

—	Steam traction.		Electric traction.			
			Traffic A.		Traffic B.	
	1907.	1908.	Single-phase current.	Three-phase current.	Single-phase current.	Three-phase current.
Amount of traffic.						
Millions of ton-kilometres per year :						
Locomotives	450	482	410		550	
Load	1,102	1,066	1,300		1,760	
Total	1,552	1,548	1,710		2,310	
Increase as compared with 1907 :						
Load, ton-kilometres	...	...	18 p. c.		60 p. c.	
Total, ton-kilometres	...	...	10 —		49 —	
Capital outlay.	Thousands of francs.					
Water-power plant	...	...	27,150	24,865	30,450	27,865
Energy distribution	...	...	2,633	6,969	2,633	6,969
Electric equipment of railway track	...	...	29,113	33,082	29,113	33,082
Increase of rolling stock necessary for increase of traffic	...	...	7,148	7,148	16,748	16,748
Total	...	...	66,044	72,064	78,944	84,664
Total running expenses.						
For the line equipment proper :						
Interest	460	506	1,164	1,323	1,164	1,323
Amortization	17	16	98	121	98	121
Renewals :						
Contact line	...	...	90	137	90	137
Locomotives and rail motor cars	207	228	245	228	245	228
Sheds, etc.	...	...	10	10	10	10
Total	684	750	1,607	1,819	1,607	1,819
For the rolling stock necessary for the increase of traffic :						
Interest, amortization and renewals	...	...	372	372	872	872
Total financial charges	684	750	1,979	2,191	2,479	2,691
Running expenses proper :						
Excluding energy (but coal included)	8,224	8,630	4,707	4,799	5,515	5,607
Energy at the contact line :						
Cost at the power station	...	...	2,172	1,989	2,436	2,229
Cost of distribution	...	...	318	868	318	868
Total for running the train service	8,908	9,380	9,176	9,847	10,748	11,395
That is, per ton-kilometer :						
of total weight, in centimes	0·575	0·605	0·535	0·575	0·465	0·493
of load hauled, in centimes	0·81	0·88	0·705	0·760	0·610	0·647

in the case of ordinary standard-gauge railways.

Technical reasons already led us to the conclusion that single-phase current is, as a rule, preferable to three-phase current for operating standard-gauge railways; and these economical results confirm that conclusion. It may hence probably be assumed to be certain that the single-phase system is that which would today be selected as the most suitable for operating standard-gauge railways.

As regards the difference of cost as compared with the present steam operation, these calculations only give a comparable figure for the cost per unit of traffic, as the proposed electric schemes were not based on the same traffic and the same time-table which apply to the existing steam traction. Projects for electric traction under exactly the same conditions as those which have actually been experienced during a given year of steam traction are meanwhile being worked out, and it appears that these will give substantially the same result as that shown in the tables : namely, that electric traction is cheaper than steam traction. If we compare the two cases which most nearly resemble each other, namely the year 1908, with steam operation, and traffic A, with electric operation, the saving effected by electric as against steam operation would amount to about 10 per cent (0·535 as against 0·605 centime [0·0840 as against 0·0950 penny per English ton-mile]) for the gross load hauled; it would naturally be still greater for the useful load hauled, namely 19 per cent (0·705 as against 0·88 centime [0·1107 as against 0·1381*d*. per English ton-mile]).

It may be added that our Commission of investigation is at present working out fresh projects for the power stations; these, together with some modifications in the proposed time-table, will give a better general scheme for the St. Gothard Railway, and at present enable us to expect final results, which when compared with those already given, will show still more in favour of electric operation.

The difference between the cost of steam traction and that of electric, water-power traction, in favour of the latter, must also become generally greater in the future and with increasing traffic; for the increase in the traffic does not involve any important increase in the maximum load, and consequently no increase is necessary in the size of the water-power plant; it is only necessary to utilize it better, and this can be done without much extra expenditure. Moreover, it is probable that the price of coal will be higher in the future, owing to a rise in wages, while power stations which are in existence and which have a long life, will be able, in course of time, to supply energy at a cheaper rate, as the greater part of the annual expenditure is not spent on wages but on interest and the capital can gradually be amortized.

As far as can at present be seen, the projects for district II of the Federal Railway will give very similar results. Differences in the case of the different networks will chiefly be caused by the unequal distribution, in the different parts of the country, of suitable water-powers; this circumstance is locally, that is to say for us in Switzerland, of great importance; but it does not affect the question of electric traction in general.

Among actual examples of the econom-

ical success of the electrification of steam railways, we may mention the branch line Neuchatel-Cortaillod-Boudry, the experience of which clearly shows the financial improvement resulting from electrification; this is, however, but a small suburban and interurban light railway with traffic which approximates rather to that of a city tramway than to that of a standard-gauge railway, and consequently in this case, as in that of nearly all previous electrifications of steam railways, simultaneous changes in the time-tables and in the traffic generally make an accurate comparison difficult. In any case, this small instance also points in favour of the electrification of steam lines, similar to the numerous instances in other countries (particularly the many instances in North America), although these are chiefly working under special conditions, for instance busy city traffic, suburban traffic, etc.

We believe that for us in Switzerland we may with confidence say : the electric operation of standard-gauge railways is today technically possible, reliable and adequate; it will give technically and economically successful results, particularly if the single-phase system is applied; when suitable water-power is available, it is already at present cheaper with us than steam operation, using coal. One main point must not, however, be forgotten : the work of electrifying the standard-gauge railways will involve an enormous capital outlay.

SECOND PART.

Description of the principal newer Swiss locomotives for electric standard-gauge traction.

(With the special collaboration of Dr. W. Kummer.)

In the last decade, the electro-technical industry has everywhere been particularly occupied in so developing electric traction, which had proved its suitability for light railways, that it would satisfy all the requirements and desiderata of standard-gauge railway operation. The construction of larger electric locomotives consequently soon became the principal new problem, to such an extent that the degree of improvement of these vehicles became the criterion of the progress attained. We consequently believe that a short description of Swiss electric locomotives will serve as a particularly good index of the state of the work done in Switzerland in the domain of electric traction. Our manufacturers have devoted much attention to this problem, and, if several of the completed equipments typify only smaller capacities, and only the newest and therefore much later designed types are comparable to the largest units built, it must be remembered that the relatively small size of our country has led us to devote our attention in the first place to light railways, and has made trials on standard-gauge railways more difficult. On the other hand, we can claim for the electro-technical industry of Switzerland the

credit that as soon as the first electric locomotives for standard-gauge railways were built, it selected that design which today is generally considered as best adapted for traction on main lines, and which in other countries only received consideration after more or less successful trials with other designs. Those which today are normal types, and are characterized by the rigid attachment of the driving motors to the frame of the vehicle, and by the use of coupling rods, either driven direct from the motor shaft, or driven from an intermediate shaft driven by the motors through spur gearing or cranks, were already used in 1898 on the narrow-gauge light railway of Stansstad to Engelberg, which is partly an adhesion line and partly rack; also since 1899, on the standard-gauge line from Burgdorf to Thun; in both cases spur gear transmission and intermediate shafts are used. Even the locomotives built in 1904 and 1905 for the experimental line from Seebach to Wettingen which became so important in the solution of the problem of what supply system to adopt, were built with motors rigidly connected to the frames and operating the driving axles through spur gearing, intermediate shafts and coupling rods. The use of coupling rods alone, without spur gearing or intermediate shafts was proposed for the Valtelina line, which had been previously operated by other forms of drive (motors built up on the driving axles), as the result of the invitation of tenders by the Adriatic railway system, in October 1902, from the Swiss firm of Brown, Boveri & Co. and the Swiss locomotive and machine works of Winterthur jointly, on the one hand, and from the Hungarian firm of Ganz & Co., on the other (1); the order for the first locomotives of this kind for the Valtelina Railway was given to the Hungarian firm of Ganz & Co. in 1903; the Swiss firms received an order in 1905 for locomotives of this type, and these locomotives were then used for electric traction in the Simplon tunnel, by joint agreement between the Swiss and Italian authorities. The method of drive which was adopted for the locomotives of the Burgdorf-Thun Railway, and the experimental Seebach-Wettingen line, has just recently been improved, in that the spur-gear transmission has been superseded by a system of connecting rods with the retention of the intermediate shaft. This improvement which was first tried with success on American railways, is at present specified in orders which some Swiss manufacturers are executing for foreign railway companies.

After this short glance at the progressive development of the mechanical transmissions used on main-line locomotives, in so far as Swiss manufacturers were concerned, we will now give a short account of the main-line electric locomotives which either are actually running on Swiss railways, or are being built for them, and also of several locomotives recently constructed by Swiss manufacturers and supplied to railway administrations in other countries, arranged according to railway.

Particulars of the general conditions of the Swiss lines in question are given in the tables and other contents of the third part of this report.

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(1) See *Elektrische Bahnen und Betriebe*, 1905, pp. 168, 267, 341.

As it is the oldest electrically-operated standard-gauge railway in Switzerland, we start with the Burgdorf-Thun Railway. This standard-gauge railway is 40·3 kilometres (25 miles) long, and the steepest gradient is 25 per mil. It uses, for hauling goods trains, an older pattern of locomotive shown in figure 1 (two axles, weight 30 tons), first used in 1899, and a newer pattern, shown in figure 2 (four

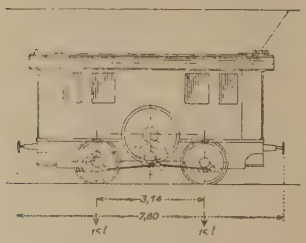

Fig. 1.
1899 locomotive of the Burgdorf-Thun Railway. Scale : 1 : 200.

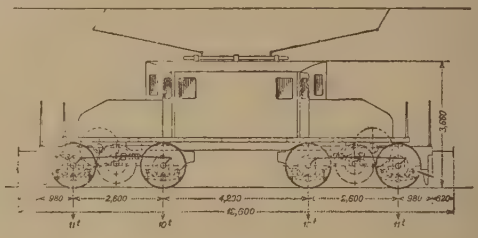

Fig. 2.
1910 locomotive of the Burgdorf-Thun Railway. Scale : 1 : 200.

axles, weight 42 tons), which began running in 1910. In both patterns the entire weight is used as adhesive weight, and the transmission from the motors to the driving axles is accomplished by means of spur gearing, intermediate shafts, and horizontal coupling rods. The current-supply system used on this railway, as is well known, is three-phase current with 40 periods with a contact-line voltage of 750 volts; the motors are of the induction type and wound for the contact-line voltage. While, however, in accordance with the then-existing state of knowledge, the motors of the older locomotives had an economical speed change, two different speeds being obtained mechanically by varying the gear ratio in the transmission, the motors of the newer locomotives are equipped electrically for four economical speeds by means of commutating poles on the motors. The normal working conditions corresponding to the nominal motor output (hour rating) are given in the following table for both types of locomotives.

Type of locomotive, Burgdorf-Thun Railway.	Speed steps, in kilometres per hour.	Tractive effort at wheel periphery, in kilograms		Output, in horse-power	
		per locomotive.	per driving axle.	per locomotive.	per motor.
1899	18	4,400	2,200	300	150
	36	2,200	1,100	300	150
1910	15·75	8,570	2,140	500	250
	21·0	7,720	1,930	600	300
	31·5	6,000	1,500	700	350
	42·0	5,140	1,285	800	400

The general arrangement of the two types of locomotive is shown in the figures; it may also be added that the older type has two rigid driving axles with a wheelbase of 3·14 metres (10 ft. 3 5/8 in.) while the newer type is equipped with two bogies each with a wheelbase of 2·6 metres (8 ft. 6 3/8 in.), and a total wheelbase of 9·4 metres (30 ft. 10 in.); it is worthy of notice that the drive of the axles is arranged unsymmetrically relatively to the bogie centres. In the older type having a total weight of 30 tons and a consequent maximum wheel-load of 7·5 tons, the weight of the electric equipment was 10 tons, while in the newer type having a total weight of 42 tons and a maximum wheel-load of 5·5 tons, the electric equipment weighs 18 tons. In both types, the diameter of the driving wheels is the same, namely 1,230 millimetres (4 ft. 7/16 in); the drive of the older locomotives had reduction ratios of 1 : 1·88 and 1 : 3·72; that of the newer locomotive has one reduction ratio of 1 : 4. The mechanical equipment of the old and new locomotives of the Burgdorf-Thun Railway was constructed by the Swiss locomotive and machine works of Winterthur and the electrical equipment by Brown, Boveri & Co., of Baden.

A few years after the Burgdorf-Thun Railway started working, the Oerlikon Company began preparations for an experimental traction scheme on the Seebach-Wettingen line (19·4 kilometres [12 miles] in length) of the Swiss Federal Railway; from the commencement, locomotive traction alone was considered and the electric system selected was single-phase alternating current with 15,000 volts on the contact line, and a periodicity of about 16 per second (lecture by Director E. Huber on 27 February 1902) (1). This line has a steepest gradient of 12 per mil and most of the traffic consists of mixed trains; it was found that locomotives weighing about 40 tons would suffice if their whole weight was used as adhesive weight. Two locomotives were built by the Oerlikon Works and the Swiss locomotive and machine works of Winterthur; they differed in the outward appearance of their bodies, and had two bogies which were spring-suspended from the locomotive frame proper. While the body of the first locomotive (built in 1904) had only one cab for the driver, the body of the locomotive built a year later, as shown in figure 3, had two cabs. Attention may be

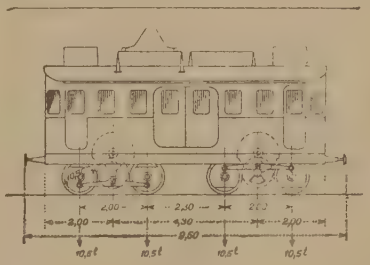

Fig. 3.
Locomotive of the Seebach-Wettingen experimental line. Scale : 1 : 200.

drawn to the fact that the older of these two locomotives was originally fitted with a converter installation for converting single-phase alternating current of at first 50 and later on 15 periods into direct current; subsequently it was however altered and equipped like the second loco-

(1) *Schweizerische Bauzeitung*, vol. XXXIX, p. 107 et seq.

motive for direct operation by single-phase commutator motors (series motors with auxiliary poles) which were supplied with current from single-phase transformers which reduced the contact-line voltage of 15,000 to 350 volts, the admissible maximum for the motors. The axles of the bogies of these locomotives are driven by means of spur gearing, intermediate shafts and horizontal coupling rods. The arrangement of the driving gear relatively to the bogie is perfectly symmetrical, because the arrangement of the bogie in the locomotive frame is such that the usual centre pin is unnecessary. The two motors have an hour rating of 250 horse-power each; this corresponds to a tractive effort of 3,400 kilograms (7,495 lb.), measured at the periphery of the wheels of the locomotive, and to a speed of 40 kilometres (24·9 miles) per hour. By changing the transformation ratio of the 2×250-kilo-volt-ampere transformers on the locomotive, the tractive effort and the speed can be regulated from 0 to 150 per cent of the normal value, in as small steps as desired; for obtaining this regulation, the one locomotive was equipped with a controller of the same construction as those used for direct-current control, while the other locomotive had an indirect control by contactors. Each bogie has a wheelbase of 2 metres (6 ft. 6 $^3/_4$ in.), and the locomotives have a total wheelbase of 6·3 metres (20 ft. 8 in.). The total weight of 42 tons, corresponding to a wheel-load of 5 $^1/_4$ tons, includes 21 tons for the electrical equipment. The wheels are 1,050 millimetres (3 ft. 5 $^3/_8$ in.) in diameter, and the reduction ratio of the gear is 1 : 3·08. In order to complete the above account, it may be mentioned that a locomotive built by Siemens-Schuckert was also used for the trials for a short time; the three-axle bogies of this were equipped with geared motors, placed intermediately to the axles, and were self-contained, as is usual with rail motor cars. The period during which all scheduled trains on the Seebach-Wettingen line were electrically hauled extended from 1 December 1907 to 3 July 1909.

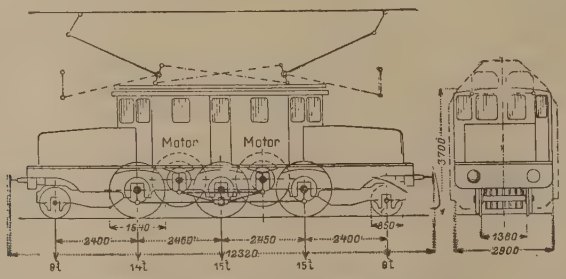

Fig. 4. — 1906 locomotive of the Simplon line. Scale : 1 : 200.

We next have to consider, from the point of view of the locomotives used, the Simplon line, which is the most important standard-gauge railway operated electrically in Switzerland. This international main line is 22 kilometres

(13·7 miles) long, and has a maximum gradient of 7 per mil; it was opened in 1906 and at once operated by means of electric traction; it uses, for the service of all classes of trains, four electric locomotives, of which the two older with six driving and four carrying wheels, as mentioned in the introduction to this section, were originally intended for use on the Valteline Railway. Two others put into service in 1907 have eight wheels, all driving. The 1906 type of locomotive having a total weight of 62 tons of which 44 tons are adhesive weight, is shown in figure 4, and the 1907 type, whose weight of 68 tons is all adhesive weight, is shown in figure 5. In both cases, the driving axles are driven by means of a parallel

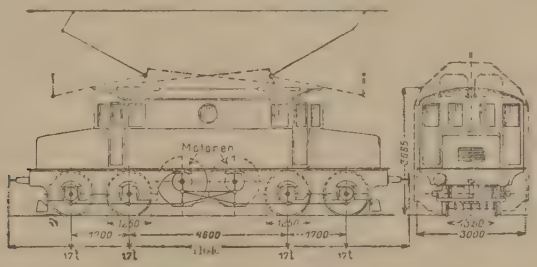

Fig. 5. — 1907 locomotive of the Simplon line. Scale : 1 : 200.

crank drive without the use of intermediate shafts. The traction system used on this railway is three-phase current of 15 periods at 3,000 volts in the contact line; the motors are induction motors, wound for the contact-line voltage, with commutating poles, giving two speed steps in the case of the 1906 locomotives and four speed steps in that of the 1907 locomotives. The normal tractive efforts corresponding to the hour rating of the motors at each speed step are given in the following table for both types of locomotives :

TYPE OF LOCOMOTIVE (SIMPLON).	Speed steps, in kilometres per hour.	Tractive effort at wheel periphery, in kilograms		Output, in horse power	
		per locomotive.	per driving axle.	per locomotive.	per motor.
1906 . . .	35	5,800	1,930	800	400
	70	4,000	1,330	1,100	550
1907 . . .	26	11,500	2,875	1,100	550
	35	10,000	2,500	1,300	650
	53	7,700	1,925	1,500	750
	70	6,400	1,600	1,700	850

It may be mentioned, as regards the arrangement of the two types of locomotives, which is shown in the figures, that in the case of the 1906 type, both driving motors are rigidly fixed in the frame on both sides of a middle driving axle which has lateral play; from this driving axle the drive is carried to the two outer driving axles, each of which is mounted in a bogie having a driving axle and a carrying axle. On the other hand, the two driving motors of the 1907 type are entirely inside of the four driving axles, of which the two outer ones are radially adjustable, being arranged on the Klien-Lindner system. The total wheelbase of the 1906 type is 9·7 metres (31 ft. 10 in.), and the maximum wheel-load is 7·5 tons; the corresponding dimensions with the 1907 type are 8 metres (26 ft. 3 in.) and 8·5 tons. Finally, it has to be mentioned that the diameter of the driving wheels of the 1906 locomotive is 1,640 millimetres (5 ft. 4 $^{9}/_{16}$ in.), and that of the trailing wheels is 850 millimetres (2 ft. 9 $^{1}/_{2}$ in.), while with the 1907 locomotive the diameter of the driving wheels is 1,250 millimetres (4 ft. 1 $^{3}/_{16}$ in.). The mechanical equipment of all the electric locomotives for the Simplon tunnel was constructed by the Swiss locomotive and machine works of Winterthur, and their entire electrical equipment by Brown, Boveri & Co., of Baden.

The electrification of the Simplon line was followed by that of the *Berner Alpenbahn* which when completed will give direct access to the Simplon. For working this line, single-phase current with 15 periods, and a contact-line voltage of 15,000 volts were chosen after the pattern of the experimental Seebach-Wettingen line. The Spiez-Frutigen section with a maximum gradient of 15·5 per mil will be first equipped; the locomotives in course of construction were, however, originally designed for the maximum gradient of 27 per mil encountered on the *Berner Alpenbahn*. There are available, for the experiments which will soon be begun, the locomotive of the Oerlikon Works and of the Swiss locomotive and machine

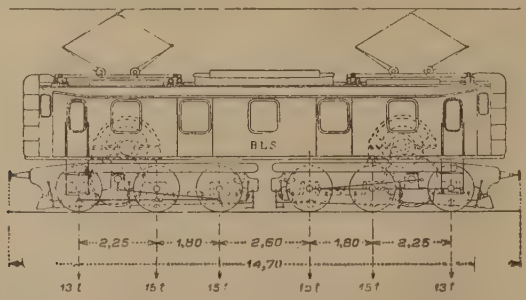

Fig. 6. — Oerlikon locomotive of the Berner Alpenbahn. Scale : 1 : 200.

works of Winterthur, shown in figure 6, and the locomotive of the " Allgemeine Elektrizitäts-Gesellschaft " of Berlin and the locomotive works of A. G. Krauss & Co., of Munich, shown in figure 7. The former of the two locomotives has six

driving axles arranged in two bogies and utilizes its whole weight of 86 tons as adhesive weight; 42 tons of this represent electrical equipment. The three axles of each bogie are driven by one single-phase series motor having an hour rating of

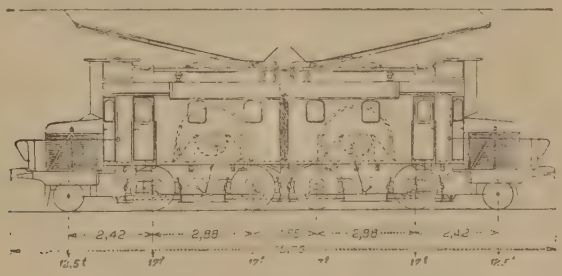

Fig. 7. — A. E. G. locomotive of the Berner Alpenbahn. Scale : 1 : 200.

1,000 horse-power, rigidly carried on the frame, by means of gearing, an intermediate shaft and coupling rods. The hour rating corresponds to a speed of 42 kilometres (26 miles) per hour, and a tractive effort of 12,000 kilograms (26,455 lb.) at the wheel periphery is developed by the locomotive; it may be added that the total wheelbase is 10·7 metres (35 ft. 1 in.), the maximum wheel-load 7·5 tons, the diameter of the driving wheels 1,350 millimetres (4 ft. 5 $^{3}/_{16}$ in.); and that the reduction ratio is 1 : 3·25. The other locomotive designed by the " Allgemeine Elektrizitäts-Gesellschaft " of Berlin is built as a double locomotive with two close-coupled half locomotives each independent of the other, each with two driving axles and one carrying axle. The driving axles of each locomotive half are driven by a Winter-Eichberg compensated single-phase commutator motor having an hour rating of 800 horse-power rigidly carried in the frame, by means of a connecting-rod transmission, an intermediate shaft, and horizontal coupling rods. Corresponding to this hour rating of the motors, the whole locomotive can develop at a speed of 40 kilometres (25 miles) per hour a tractive effort of 10,800 kilograms (23,810 lb.) at the wheel periphery. It may also be mentioned that the total wheelbase of each locomotive half is 5·3 metres (17 ft. 4 $^{11}/_{16}$ in.) and that of the entire locomotive 12·45 metres (40 ft. 10 in.); the maximum wheel-load is 7·5 tons. Of the total weight of 93 tons, 50 tons is represented by the electrical equipment, and 68 tons can be utilized for adhesion. The diameter of the driving wheels is 1,270 millimetres (4 ft. 2 in.) and that of the carrying wheels is 850 millimetres (2 ft. 9 $^{1}/_{2}$ in.). The regulation of the tractive effort and of the speed of the locomotive of the Oerlikon Company, as well as that of the " Allgemeine Elektrizitäts-Gesellschaft " of Berlin, can be set for a very great number of speed steps, thanks to the application of transformers with variable transformation ratios.

Now although the attempts to electrify other lines of the Swiss railway system have not developed beyond the project

stage, yet the manufacturers in Switzerland are at present employed in constructing electric locomotives for different railway systems in the neighbouring countries.

Attention may thus be drawn more particularly to the electrification of the Wiesental line, which has been undertaken by the Baden State Railway; moreover, a small part of this line is in our country. The firm Brown, Boveri & Co., conjointly with the Karlsruhe Machine Company of Munich, are building two passenger-train locomotives (shown in fig. 8) for the Wiesental line. These are single-phase locomotives for a contact-line

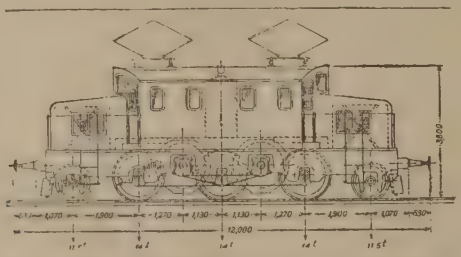

Fig. 8. — Passenger-train locomotive by Brown, Boveri & Co., for the Wiesental line. Scale : 1 : 200.

voltage of 10,000 volts and 15 periods. The driving arrangement which was chosen for this type of locomotive which is equipped with two repulsion motors on the Déri-Brown Boveri system, each with an hour rating of 475 horse-power, wound for 1,000 volts, and has ten wheels, six coupled, is exactly similar to that of the older Simplon locomotives (see figs. 4 and 8) with the exception of the small differences occasioned by the rigid arrangement of all driving axles. Corresponding to this hour rating of the motors, this locomotive can develop a tractive effort of 4,200 kilograms (9,260 lb.) at the wheel periphery at the normal speed of 61 kilometres (38 miles) per hour. The total weight of this locomotive is 65 tons; of this 42 tons are available for adhesion, corresponding to a maximum wheel-load of 7 tons. The total wheelbase is 8·6 metres (28 ft. 2 $^{5}/_{8}$ in.); the driving-wheel diameter is 1,400 millimetres (4 ft. 7 $^{1}/_{8}$ in.) and the carrying-wheel diameter 990 millimetres (3 ft. 3 in.). The control of the motors is noteworthy for its simplicity; it is effected by shifting one of the two sets of brushes per pair of poles, which is a characteristic of the Déri motors. The weight of the electrical equipment of this locomotive amounts of 31 tons.

The Swiss industry is also taking an extensive part in the locomotive competition for the Midi Railway. The Midi Railway Company, as we know, has drawn up a comprehensive electrification scheme for its lines in the Pyrenees and intends already this year to start trials of electric operation on the line from Perpignan to Villefranche-Vernet-les-Bains, which is about 16 kilometres (10 miles) long. Trials are going to be made on this line with several electric locomotives designed to

have an hour rating of 1,500 horse-power. The mechanical parts of two of these locomotives, which are both to have ten wheels, six coupled, are at present being built in the work shops of the Winterthur locomotive and machine works. Figure 9 shows a sketch of one of these locomotives, the electrical equipment of which is being provided by Brown, Boveri & Co., of Baden; figure 10 represents the other, the

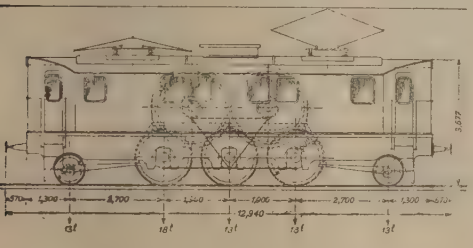

Fig. 9.
Winterthur-Brown, Boveri & Co. locomotive for the Midi Railway. Scale : 1 : 200.

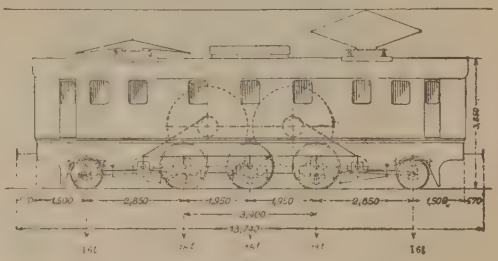

Fig. 10.
Winterthur-Thomson-Houston locomotive for the Midi Railway. Scale : 1 : 200.

electrical equipment of which is being prepared by the French Thomson Houston Co. Corresponding to the hour rating of these locomotives, a tractive effort of 9,000 kilograms (19,840 lb.) at the wheel periphery can be developed at 45 kilometres (28 miles) per hour. The locomotive equipped by Brown, Boveri & Co., employs a parallel crank drive, similar to that of the locomotive built by the same firm for the Wiesental line; but in the present case, the distance between the plane of the driving axles and that of the motor shafts is considerably greater. Of the total weight of 80 tons, 54 tons are utilized for adhesion; it may also be mentioned that the maximum wheel-load is 9 tons, and the electrical equipment used weighs 42 tons, including the Déri motors; the total wheelbase is 9·20 metres (30 ft. 2 in.), the diameter of the carrying wheels 850 millimetres (2 ft. 9 $^1/_2$ in.), and that of the driving wheels 1,600 millimetres (5 ft. 3 in.). In the case of the locomotive equipped by the Thomson Houston Co. for the Midi Railway, the transmission from the motors to the driving axles consists of a completely symmetrical arrangement of connecting rods and cranks and two intermediate shafts. Of the total weight of 86 tons of this locomotive, 54 tons are utilized for adhesion and the maximum wheel-load is 9 tons. The electrical equipment accounts for about 46 tons of the total weight. The total wheelbase is 9·6 metres (31 ft. 6 in.), the diameter of the carrying wheels 850 millimetres (2 ft. 9 $^1/_2$ in.) and that of the driving wheels 1,310 millimetres (4 ft. 3 $^5/_8$ in.). The electrical system adopted by the Midi Railway is single-phase current with 16 $^2/_3$ periods and a contact line voltage of 12,000 volts.

An electric locomotive is also going to be supplied by Brown, Boveri & Co. for the Dessau-Bitterfeld line of the Prussian-Hessian State Railway. This goods loco-

motive is shown in figure 11; its mechanical equipment was supplied by the

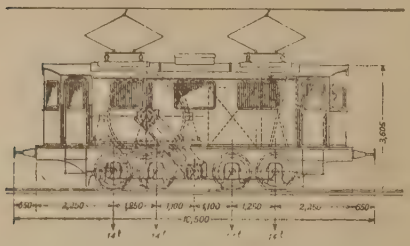

Fig. 11.
Locomotive by Brown, Boveri & Co.
for the Dessau-Bitterfeld line. Scale : 1 : 200.

Hanover Machine Co. (formerly G. Egestorff). Its total weight of 56 tons is carried on four coupled rigid axles, which are driven by a 900-horsepower Déri Motor, which is placed at a much greater height, by means of a system of connecting rods and an intermediate shaft. Corresponding to the hour rating, a tractive effort at the wheel periphery of 6,500 kilograms (14,330 lb.) can be developed at a normal speed of 25 kilometres (15·5 miles) per hour. The total wheelbase is 4·5 metres (14 ft. 9 in.), and the diameter of the driving wheels is 1,050 millimetres (3 ft. 5 $^3/_8$ in.) The electrical system adopted is 15-period single-phase current with a contact-line voltage of 10,000 volts; the weight of the electrical equipment is 26 tons.

Finally, we must here mention the intended electrifications on the Paris-Lyons-Mediterranean Railway, for which the Alioth Electrical Company has built the transformer locomotive shown in figure 12, having an hour rating of

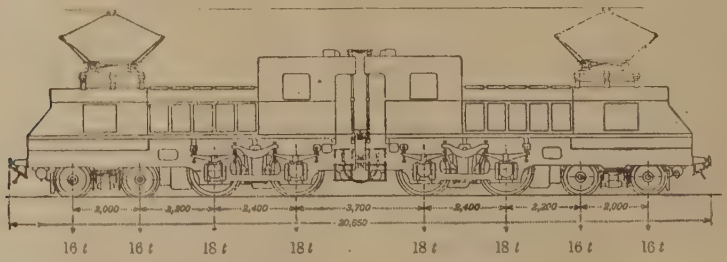

Fig. 12. — E. G. Alioth locomotive for the Paris-Lyons-Mediterranean Railway. Scale : 1 : 200.

1,800 horse-power, on the Auvert-Ferrand-Alioth system. This locomotive, consisting of two tight-coupled units, is to be used for the express train service (up to 120 kilometres [74·5 miles] per hour). Each of the units has two driving axles and two carrying axles, arranged in a bogie. The driving axles are driven by means of direct-current motors, which are spring-suspended from both sides of the frame and transmit the power to the driving axles through elastic couplings to bevel wheels having a reduction ratio of 1 : 3. At the normal speed of 60 kilometres (37·3 miles) per hour this locomotive develops a tractive effort at the wheel periphery of 8,000 kilograms (17,630 lb.); its electrical equipment weighs 72 tons and the total weight reaches 136 tons. The control of the

motors of this locomotive, the mechanical equipment of which was supplied by the Chantiers de la Buire, of Lyons, is accomplished by varying the direct-current voltage at the terminals of the converter by the simple means of brush shifting, for which a special direct-current regulating motor is employed, which is fed from a small converter set, and affords a delicate means for the regulation of the field strength. The diameter of the driving wheels is 1,500 millimetres (4 ft. 11 in.) and that of the carrying wheels is 1,000 millimetres (3 ft. 3 $^3/_8$ in.); the maximum wheel-load is 9 tons. The running trials of this peculiarly-equipped locomotive are being carried out on the Cannes-Grasse line, which is equipped for working with 13,000 volt single-phase current and 25 periods.

THIRD PART.

Tabular summary of particulars of electric railways in Switzerland and other countries.

The annexed tables contain statistics and other particulars concerning the specially noteworthy railway electrifications in Switzerland and in other countries, about which the author received information in answer to the list of questions sent out by the Congress, or about which information was collected by the Swiss Commission of investigation.

Those particulars were selected which seemed to us specially important as giving as comprehensive a view as possible of the electric operations in question.

Before giving the tables, we will preface them by some general information about the railways given in those tables.

Swiss electric railways.

Freiburg-Murten-Ins. — The Murten-Ins section of the line which connects these three towns on the Swiss plateau was originally built for electric operation, and it was also intended to electrify the existing Freiburg-Murten section. The chief object aimed at was the utilization of the cheap water-power which could be obtained from the State power station at Freiburg and so remedy the unsatisfactory financial results of the existing steam line, while at the same time giving a more frequent train service, in spite of the small total amount of traffic. Judging from the design, gauge and composition of the trains, the line is an ordinary standard-gauge railway; according to the Swiss classification, it is however only a « *Nebenbahn* » (branch line or light railway); it carries but little traffic. The latter condition has given rise to the use of substations with storage batteries, so as to make it possible to use a small water-power, and utilize it better; this led the Oerlikon Works, who supplied the electrical equipment, to adopt the direct-current and third-rail system, which had till then not been practically applied in Switzerland. (The older Mont Salève Railway near Geneva is on French soil.) Since the opening in July 1903, more

powerful rail motor cars have been introduced. (See *Schweizerische Bauzeitung*, 1901, vol. XXXVII, p. 226.)

The Montreux-Bernese Oberland Railway is a metre-gauge (3 ft. 3 3/8 in.) light railway carrying nevertheless a considerable traffic, chiefly tourists; its special feature ist he large amount of power supplied by the direct-current overhead contact-line system; 750-volt motors are used (constructed by the Alioth Co., of Münchenstein-Basel). As it is an Alpine railway, rising from a height of about 400 metres (1,312 feet) to one of about 1,280 metres (4,200 feet) above sea level, it has many steep gradients and many interesting constructive works. It runs from Montreux on the lake of Geneva to Zweisimmen in the Bernese Oberland, and was initially built as an electric railway, as it was desired to utilize neighbouring water-powers, and also to use balancing batteries, because of the large power fluctuations. The first section was opened in 1901 and the entire line in 1905. (See *Schweizerische Bauzeitung*, 1901, vol. XXXVIII, p. 224.)

The Burgdorf-Thun line is our first three-phase standard-gauge railway which was built for electric traction; the object was to obtain, by means of water-power, a cheap service on this branch line which carries but little traffic; for if steam traction had been used, the curves and gradients would have made a large coal-consumption necessary. The three-phase system was recommended both by the manufacturers of the electric equipment, Brown, Boveri & Co., as being cheaper than the only other system available (direct current with several substations), and also by the Kander power station, which supplied the current (40-period three-phase current). All trains, passenger trains consisting of rail motor cars or hauled by locomotives, and goods trains hauled by locomotives, have been operated electrically since the opening of the line in July 1899. (See *Schweizerische Bauzeitung*, 1900, vol. XXXV, p. 1.)

Simplon Tunnel. — This electric railway embraces the well-known tunnel section between and including the stations of Brigue and Iselle on the Simplon international standard-gauge main line.

The electrification of this line, which was very desirable owing to smoke troubles in this long tunnel, particularly in the interest of the locomotive crews, was effected in a very short period of time, thanks to the existence of available water-powers near the tunnel which had been used during its construction; moreover, the firm of Brown, Boveri & Co., made an offer to equip and operate the line immediately, at first as an experiment; finally the Italian State Railway kindly allowed several of its electric locomotives to be used to begin with. This made it possible to begin electric operation as soon as the line was opened, on 1 June 1906; it extends to the whole service except to a pair of trains which must be hauled by steam, because the steam locomotives used on the Iselle-Domo d'Ossola section come from the Swiss depot at Brigue and must be returned there. All trains, both goods and passenger, are exclusively hauled by locomotives operated by means of three-phase current with 3,000 volts on the contact line; this is the most important

service operated with three-phase current. (See among others *Zeitschrift des Vereins deutscher Ingenieure*, 1907, vol. LI, p. 382; *Schweizerische Bauzeitung*, 1909, vol. LIV, p. 223.)

Seebach-Wettingen. — This branch line of the Swiss State Railway, near Zurich, is equipped and operated like a main line. The Oerlikon Works has equipped it at its own expense, in order to carry out extensive trials of high-tension single-phase current; since 1904 different types of locomotives have been tried; at first, for a short time, transformer locomotives (Ward Leonard) were used, and then locomotives with single-phase commutation motors were definitely adopted. From 1 December 1903, until 3 July 1909, all booked trains were hauled electrically; occasionally, and sometimes regularly, certain trial trains were run, in order to test the single-phase system, the motors and the current-supply appliances, in practical service.

Locarno-Valle Maggia. — The Maggia valley line runs from Locarno up the valley to Bignasco; the gradients are moderate. It is a metre-gauge (3 ft. $3\,^3/_8$ in.) light railway for local and tourist traffic, and it was originally built for electric traction, because water-power was available close to the line, and also because it was desired to operate a frequent light-train service. On the proposal of the Oerlikon Works it was equipped, for reasons of economy, so as to use single-phase current at high voltage in the contact line; it was opened in 1908, and is accordingly the first single-phase railway in Switzerland. (For description see *Schweizerische Bauzeitung*, vol. LI, p. 60.)

Foreign electric railways.

Paris-Orleans. — The information given concerning this electrical operation applies to that main-line section of this standard-gauge railway, which is in and near Paris; the greater part of this section is within township limits, and the direct-current and third-rail system is applied. The whole section is equipped in this way; from Quay d'Orsay to Austerlitz station all trains are hauled electrically, while from Juvisy to Quai d'Orsay, only the passenger trains are so hauled. In addition to long-distance trains, there is a very heavy suburban traffic, originally operated by steam; the line was electrified chiefly to mitigate the great smoke nuisance caused by the heavy traffic in the many open cuttings and tunnels within the township limits. Electric traction began in 1900. (See among others *Revue générale des chemins de fer*, 1898, February and November, 1900, August and December.)

Paris (Invalides)-Versailles. — A standard-gauge railway, with conditions and equipment similar, and reasons for electrification analogous to the last case; in several city stations, in the underground stations "Invalides" and in the Meudon tunnel (with a gradient of 18 per mil), the smoke nuisance was particularly disagreeable. Only passenger trains are electrically hauled; on the section to Moulineaux since 1900, on that to Meudon since 1901 and on that to Versailles since 1902.

Lancashire & Yorkshire Railway. — This has electrified its Liverpool to Southport branch, which is a suburban line of an important standard-gauge railway, but

is also partly an elevated line. This was done in order to obtain a better service for this heavy suburban traffic, affecting many stations, by obtaining as great starting accelerations as possible; since March 1904, the whole traffic is operated electrically. The direct-current and third-rail system was adopted. (See *The Tramway and Railway World*, 1904, April, and *Proceedings of the Institution of Mechanical Engineers*, 1909, April, pp. 423 et seq.)

North Eastern Railway. — Suburban railway under similar conditions to the last, between Newcastle-on-Tyne and Tynemouth, and various seaside places on the German Ocean. Electric traction for passenger trains by means of direct current and third rail since July 1904; goods traffic is still hauled by steam.

Midland Railway. — Here again it is a suburban line of a large town, with a very dense and fast passenger traffic, which has been electrified, more especially with a view to the collection, on a large scale, of information about electric traction generally and in particular about the single-phase system selected; since April 1908, all trains have been electrically hauled. (See, among others, *Electrotechnische Zeitschrift*, 1909, vol. XXX, p. 914, and *Proceedings of the Institution of Civil Engineers*, vol. CLXXIX, pp. 47 et seq.)

Milano-Varese-Porto Ceresio. — This line is a standard-gauge ordinary railway, and although not considered a main line, carries rather heavy traffic on certain sections, chiefly the suburban passenger traffic of the large city of Milan. The railway was equipped for electric traction, in order to deal quickly with a dense traffic, and thus to compete successfully with a neighbouring steam line. The system adopted includes direct current, third rail, substations and balancing batteries. Details are to be found, inter alia, in a special memoir issued by the Italian State Railway, and also in *Éclairage électrique*, vol. XXIX, p. 175.

Valtelina Railway. — The well-known standard-gauge branch line from Lecco, along the Lake of Como to Chiavenna and going up to Sondrio in the Valtelina. Originally a steam line with no considerable traffic, it was electrified in order to collect information about electric traction when large water-powers are used: the three-phase system was adopted on the proposal of the contractors for the electrical equipment, Messrs. Ganz & Co. Numerous tunnels rendered electrification particularly desirable; and so also did the desire to stimulate the tourist traffic by giving it greater facilities. (See the memoir of the Italian State Railway, and also *Elektrische Bahnen und Betriebe*, 1904-1907.)

Table 1. **Particulars of the railway lines.**

RAILWAY.	Freiburg-Murten-Ins.	Montreux-Bernese Oberland.	Burgdorf-Thun.	Simplon.	Seebach-Wettingen.	Locarno-Valle Maggia.	Paris-Orléans.	Paris-Versailles.	Lancashire & Yorkshire Railway.	North Eastern Railway.	Midland Railway.	Milan-Varese-Porto Ceresio.	Valtelina.
Length of railway, kilometres	32·2	62·0	40·3	22·0	19·4	27·3	23·0	17·65	51·5	48	30·6	73·0	105·7
Number of tracks	1	1	1	1	1	1	2	2	2 (4)	2 (4)	2 (4)	2 (1)	1
Gauge, millimetres	1,435	1,000	1,435	1,435	1,435	1,000	1,435	1,435	1,435	1,435	1,435	1,435	1,435
Number of stations	10	24	16	2 (3)	6	13	9	11	29	25	...	17	25
Mean distance between stations, kilometres	3·6	2·7	2·7	22 (11)	3.2	2·3	2·6	1·8	1:8	1·9	...	4·5	4·4
Steepest gradient, per mil	30	67	25	7	12	33	11	10	10	33	14	20	22
Total rise and fall in one direction, metres	312	1,903	429	90	92	262	42	113·5	13·4	...	...	370	248
Radius of sharpest curve, metres	200	80 (37 and 40)	250	300	300	100	150	...	240 (140)	240	190	300	200
Type of rail	Vignoles.	Vignoles.	Vignoles.	Vignoles.	Vignoles.	Vignoles.	Vignoles	Vignoles.	Vignoles.	Vignoles.	Vignoles.	Vignoles.	Vignoles.
Length of rails, metres	...	...	12	12	12	...	8 and 11	...	9	9	18	9 and 12	9 and 12
Weight of rails, kilograms per metre	33	24·3	36	49 (46 and 48)	36	...	42	46	39	30	39	37	37
Weight of track, kilograms per metre	...	...	137 with iron sleepers, 145 with wooden sleepers	...	...	...	...	...	...	...	...	...	...
Greatest permissible wheel-load, tons	...	...	(7·5)	9	(7·5)	...	9	8	10	10	...	7.5	7.5
Greatest permissible speed, kilometres per hour	...	...	60	75	...	...	120	100	100	75	80	90	60

Table 2. **Particulars of ele**

RAILWAY.	*Freiburg-Murten-Ins.*	*Montreux-Bernese Oberland.*
Type of contact line	Third rail, at the three chief stations single-wire overhead contact line.	Single-wire overhead contact line.
Kind of current	Direct current.	Direct current.
Periods per second	0	0
Contact-line voltage	800	750/1,000
Cross-section of contact-line, in square millimetres.	Equivalent to 410 square millimetres of copper with 2 × 100 copper bonds.	2 × 50 on 10·7 kilometres. 2 × 63 on 51·9 kilometres.
Method of support and height of contact line	Mounted on ambroin insulators.	On brackets from wooden poles, at a he of 4·8 to 5·6 metres.
Insulation of contact line	Ambroin insulators with cast-iron caps.	Double insulation as on tramways.
Type of return	Both running rails.	Both running rails.
Rail bonds	Various types.	Fishplates, plastic metal and cross bon
Method of feeding	Converter substations.	Converter substations and supplemen feeder cables.
Number of feeding points	2	5 (Transformer substations).
Mean length of railway fed from one feeding point, in kilometres.	16·1	12·5
Equipment of feeding points	At each substation, two three-phase to direct current converters of 135 kilowatts with charging dynamo and battery of 400 cells, capacity 390 ampere-hours.	At each, a three-phase to direct current verter with battery of 390 cells, capa 390 ampere-hours.
Type of long-distance line between power station and feeding point.	Three-phase aerial line, 8,000 volts, 50 periods.	Three-phase aerial line, 8,000 volts, 50 riods.
Particulars of the power station of the railway.	Current supplied by the Hauterive power station of the canton of Freiburg; about 1,000 horse-power available for this railway.	Current supplied by the Montbovon p station, and eventually from the Ha rive power station of the canton of burg; about 6,000 horse-power avail

ion systems. Table 2.

Burgdorf-Thun.	*Simplon.*	*Seebach-Wettingen.*	*Locarno-Valle Maggia.*
ble-wire overhead contact line.	Double-wire overhead contact line.	Single-wire overhead contact line.	Single-wire overhead contact line.
Three-phase current. 40 750	Three-phase current. 15 3,000	Single-phase current. 15 15,000	Single-phase current. 20 5,000
50 per phase.	2 × 50 per phase. (At stations only 1 × 50.)	50	50
ross wires, at a height of 5 metres.	Common support in tunnel for both phases, spaced 1,000 millimetres apart.	Partly trolly-pole line at a height of 5 to 6 metres, placed at the side of the track; partly contact-bow line with catenary suspension, at a height of 6 metres.	Trolly-pole line at a height of 4·3 to 5·3 metres; contact-bow line in Locarno.
ible insulation as on tramways.	Double by means of porcelain and ebonite.	Simple by means of porcelain.	Simple, protected by automatic circuit breaker should an insulator break.
Both running rails.	Both running rails, cross-section 6,200 square millimetres.	Both running rails.	Both running rails.
plates, plastic metal and cross onds.	Fishplates, 2 × 3,950 square millimetres, with plastic metal.	Various types.	Copper bonds.
Transformer substations.	Direct from the two power stations.	Direct from the power station.	Direct from the power station.
14	2	1	1
3·0	11	19·4	27·3
nsformer substations for reducing 5,500 to 750 volts. At each station, one transformer with a continuous output of 200 kilowatts.	Identical with the power station installation.	Identical with the power station installation.	Identical with the power station installation.
ee-phase aerial line, 16,000 volts, n special poles, generally placed longside the railway.	Only a very short line to the railway at each end.	Three-phase aerial line, 16,000 volts, on special poles, generally placed alongside the railway.	Only a very short line to the railway at each end.
rent supplied under contract from he Kander power station, where wo special 1,200 horse-power ydro-electric sets supply the railway. Generator voltage, 4,000 volts. Very limited water storage.	Own water-power plants at Brigue and Iselle. At Brigue two turbines of 600 horse-power each drive together one generator. At Iselle, a double turbine of 1,500 horse-power with generator. No storage.	Own transformer plant for transforming from three-phase. Two sets of about 600 kilowatts each, with balancing battery of 375 cells, with a storage capacity of 592 ampere-hours.	Own generators in Ponte Brolla power station, with two 600 horse-power turbines and no storage.

Table 2. (*Continued.*) **Particulars of elec**

RAILWAY.	*Paris-Orléans.*	*Paris-Versailles.*	*Lancashire & Yorkshire Railw*
Type of contact line	Third rail.	Third rail.	Third and fourth rails.
Kind of current	Direct current.	Direct current.	Direct current.
Periods per second	0	0	0
Contact-line voltage	600	550	600
Cross-section of contact line, in square millimetres.	Equivalent to 1,200 square millimetres of copper (in places, to 1,000 square millimetres).	Equivalent to 650 square millimetres of copper.	Equivalent to 650 square m metres of copper.
Method of support and height of contact line.	Third rail placed alongside.	Third rail weighing 46·8 kilograms per metre.	Third rail placed alongsid
Insulation of contact line	Asphalted wood.	Paraffined wood.	Simply 152-millimetre cu of artificial granite pla 3·05 metres apart.
Type of return	Both running rails.	Both running rails.	Both running rails and the fo rail.
Rail bonds	Copper bonds.	Copper bonds, with cross bonds.	Copper bonds, without cr bonds.
Method of feeding	Converter substations.	Converter substations.	Converter substations.
Number of feeding points	3	3	5
Mean length of railway fed from one feeding point, in kilometres.	7·7	5·9	10
Equipment of feeding points	Three-phase to direct current converters, one at Ivry power station, also at Ablon and Quai d'Orsay, total eight 250 kilowatt converters. Batteries of 1,100, 1,500 and 1,100 ampere-hours.	Three-phase to direct current converters, altogether 12 sets, total 3,600 kilowatts, without accumulator batteries.	Three-phase to direct curr converters, each with 600 k watt machines and batteri 270 (in one case 290) cells, 1,000 to 1,600 ampere-ho
Type of long-distance line between power station and feeding point.	Three-phase long-distance cable line, 5,500 volts, 25 periods.	Three-phase long-distance cable line, 5,000 volts, 25 periods.	Three-phase long-distance c line, 7,500 volts, 25 period
Particulars of the power station of the railway.	Own plant in Ivry, 3 × 1,000 kilowatts, steam-driven generators.	Own steam plant at Moulineaux, 7,200 kilowatts, three-phase current at 5,000 volts.	Own plant with steam eng and steam turbines, total 1 to 15,000 horse-power.

tion systems.

Table 2. (*Continued.*)

North Eastern Railway.	*Midland Railway.*	*Milan-Varese-Porto Ceresio.*	*Valtelina.*
rd rail as a rule; single-wire over-ead contact line along the quay.	Single-wire overhead contact line.	Third rail.	Double-wire overhead contact line.
Direct current. 0 600	Single-phase current. 25 6,600	Direct current. 0 650	Three-phase current. 15 3,000
...	70	Equivalent to 570 square millimetres of copper.	50 per phase.
rd rail laid between the running ails, insulator every 27 metres.	Catenary suspension from wooden poles with gantry above the track, at a height of 5·5 metres; exceptionally from lattice poles.	Third rail weighing 45 kilograms per metre.	Suspended from cross wires; at a height of 6 metres in the open and of 4·6 metres in tunnels.
Insulators of artificial granite.	Simple insulation.	Insulation of artificial granite.	Double insulation.
oth running rails of the tracks.	Both running rails.	Both running rails.	Both running rails.
opper bonds, with cross bonds.	Copper bonds, with cross bonds.	Copper bonds, with cross bonds.	Copper bonds, with cross bonds.
Converter substations.	Direct from the power station.	Converter substations.	Converter substations.
5	1	5	9
9·6	30·6	14·5	11·8
ree-phase to direct current convert-ers, altogether 13 sets, total 10,400 ilowatts, without accumulator bat-eries.	Identical with the power station installation.	Three-phase to direct current converters, total 4,000 kilowatts. At four substations there are batteries with a total of 1,865 ampere-hours.	Three-phase transformer substations, each with a normal output of 300 kilowatts and a maximum output of 1,200 kilowatts.
ree-phase long-distance cable line, 750 volts, 40 periods.	Direct from the power station to the overhead line, without long-distance line.	Three-phase aerial line, 12,000 volts, 25 periods.	Three-phase aerial line, 20,000 volts, 15 periods.
rent purchased from outside supply aving steam-turbine generating ets; 9,000 kilowatts, three-phase urrent.	Own direct-current power station, with gas-engine sets of 1,100 horse-power generating direct current, with battery of 230 cells, 1,080 ampere-hours. Two direct to single-phase current converters, with a continuous output of 150 to 200 kilowatts each, and capable of a momentary output of 900 kilowatts.	Own steam plant at Tornavento, 3 × 750 kilowatts, three-phase current at 13,000 volts.	Own water-power plant at Morbegno, 3 × 10,500 kilowatts, three-phase current at 20,000 volts. No water storage.

Table 3. **Particulars of elec**

Names of railways and types of locomotives	*Burgdorf-Thun.*		*Simplon.*		*Seebach-Wettingen.*		*P*
	Type 1899.	Type 1910.	Type 1906.	Type 1907.	Type I and II.	Type III.	Type 190
Number of locomotives	2	1	2	2	2	1	8
Number of axles. Driving axles	2	4	3	4	4	6 (4)	4
Number of axles. Carrying axles	0	0	2	0	0	0 (2)	0
Arrangement of axles	B	2 bogies.	1 C 1	D	2 bogies.	2 bogies.	2 bogies
Total weight, tons	30	42	62	68	42	75 (68)	50
Adhesive weight, tons	30	42	44	68	42	75 (45)	50
Weight of electric equipment, tons	10	18	29	35	21	33 (25)	18·5
Wheel-load, tons	7·5	5 to 5·5	4·5 to 7·5	8·5	5·25	6·25	6·25
Length over buffers, metres	7·8	12·6	12·30	11·64	9·5	13·7	10·6
Total wheelbase, metres	3·14	9·4	9·7	8 0	6·3	10·1	7·27
Diameter of driving wheels, millimetres	1,230	1,230	1,640	1,250	1,050	1,100	1,245
Diameter of carrying weels, millimetres	0	0	850	0	0	0	0
Class of motors	Three-phase induction.	Three-phase induction.	Three-phase induction.	Three-phase induction.	Single-phase series.	Single-phase series.	Direct-current series.
Motor voltage, volts	750	750	3,000	3,000	300	350	600
Motor periodicity	40	40	15	15	15	15	0
Hour rating, horse-power per motor	150	400	550	850	250	225	230
Number of motors	2	2	2	2	2	6 (4)	4
Method of drive of motors	Gear wheels and cranks.	Gear wheels and cranks.	Parallel cranks.	Parallel cranks.	Gear wheels and cranks.	Gear wheels.	Gear whee
Gear ratio	1 : 1·88 and 1 : 3·72	1 : 4	1 : 1	1 : 1	1 : 3·08	1 : 3·72	1 : 2·23
Motor control	Resistance regulation in rotor.	Pole changing.	Pole changing and resistance regulation in rotor.	Pole changing and regulation of stator voltage by means of auto-transformers.	Stator voltage by means of main transformers.	Stator voltage by means of main transformers.	Resistanc regulator Multiple control.
Normal tractive effort of locomotive at wheel periphery, in kilograms.	4,400 and 2,200	(8,570, 7,720) (6,000, 5,140)	5,800 and 4,000	(11,500, 10,000) (7,700, 6,400)	3,400	8,100 (5,400)	6,000
Normal speed of locomotive, kilometres per hour.	18 and 36	(15·75, 21·0) (31·5, 42·0)	35 to 70	(26, 35) (53, 70)	40	45	42
Maximum speed, kilometres per hour	36	60 (Downhill).	70 to 75	70 to 75	60	60	75
Current-collecting device	Bow.	Bow.	Bow.	Bow.	Bow and rod.	Bow and rod.	Sliding sho
Number and output of main transformers, kilovolt-amperes.	0	0	0	0	2 × 250	2 × 500	0
Brake system	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compresse air.

notives in use. Table 3.

ns.		Paris-Versailles.		North Eastern Railway.	Milan-Varese.	Valtellina.			
pe 1904.	Type 1906.	Gearless type.	Geared type.	Quay locomotive.	Goods Locomotive.	Type 34 (1902).	Type 36 (1904).	Type 38 (1906).	Type Giovi.
3	1	10		2	1	2	3	4	2
4 0	4 0	4 0	4 0	4 0	4 0	4 0	3 2	3 2	5 0
ogies.	2 bogies.	2 bogies.	2 bogies.	2 bogies.	2 bogies.	2 close-coupled trucks.	1 C 1	1 C 1	O E O
55	55	50·9	50·9	56·2	35	46	62	62	60·2
55	55	50·9	50·9	56·2	35	46	42	42	60·2
18·5	18·5	22	22	...	...	31·5	32	32	28·2
6·9	6·9	6·4	6·4	7	4·4	11·5	5·7	5·7	6
11·4	...	13·0	13·0	...	...	10·3	11·3	11·54	9·5
8·05	...	11·6	11·6	...	...	6·63	9·5	9·5	6·12
1,245	1,245	1,310	1,310	...	...	1,400	1,500	1,500	1,070
0	0	0	0	0	0	0	850	850	0
irect- rrent eries.	Direct-current series.	Direct-current series.	Direct-current series.	Direct-current series.	Direct-current series.	Three-phase induction.	Three-phase induction.	Three-phase induction.	Three-phase induction.
600	600	550	550	550	650	3,000	3,000	3,000	3,000
0	0	0	0	0	0	15	15	15	15
230	230	150	150	100	150	225	600	1,200, 1,500 (Cascade coupled, 850,	1,000
4	4	4	4	4	4	4	2 (Double motors)	2	2
r wheels.	Gear wheels.	Axle motor with hollow shaft.	Gear wheels with hollow shaft.	Gear wheels.	Gear wheels.	Axle motor.	Parallel cranks.	Parallel cranks.	Parallel cranks.
: 2·23	1 : 2·23	1 : 1	1 : 2·57	...	1 : 3·53	1 : 1	1 : 1	1 : 1	1 : 1
istance ulator. ultiple ntrol.	Resistance regulator. Multiple control.	Resistance and series-parallel control.	Resistance and series-parallel control.	Resistance and multiple control.	Resistance and series-parallel control.	Resistance in rotor.	Cascade coupling and rotor resistance.	Cascade coupling and rotor resistance.	Cascade coupling and rotor resistance.
6,000	6,000	4,000	4,000	6,700	4,000	7,200	7,800, 5,100	9,000 7,600, 6,300	10,300, 12,300
42	42	40	40	23	40	33	32, 64	25·5 42, 64	22, 44
75	75	100	100	23	90	33	64	64	44
ng shoe.	Sliding shoe.	Sliding shoe.	Sliding shoe.	Bow.	Sliding shoe.	Bow.	Bow.	Bow.	Bow.
0	0	0	0	0	0	0	0	0	0
pressed ir.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.	Compressed air.

Table 4. **Particulars of**

Name of railway and type of rail motor cars.	*Freiburg-Murten-Ins.*	*Montreux-Bernese Oberland.*		*Burgdorf-Thun.*	*Locarno-Valle Maggia.*	*Paris-Orléans.*	*Pa*
		Light.	Heavy.				Car with two moto
Number of rail motor cars.	4	3	19	6	3	7	3
Number of driving axles	4	4	4	4	4	4	4
Total number of axles	4	4	4	4	4	4	2
Is there a bogie?	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Total weight, tons.	33-42	22·2-22·5	23·7-27·5	32	29·7	42	23·5
Weight of electric equipment, tons.	12	8·3	8·3-8·8	10	...	...	6·5
Length over buffers, metres	17·3-19·8	13·7	13·7-14·0	16·3	16·0	...	12·3
Total wheelbase, metres.	14·0-14·1	10·4	10·3	11·7	10·0		
Distance between bogies centres, metres	11·5	8·5	8·5	9·5	7·5	...	Mac Gui bogie.
Wheelbase of bogie, metres.	2·6	1·9	1·8-1·9	2·2	2·5		
Diameter of driving wheels, millimetres.	1,010	850	850	1,020	860	...	850
Diameter of carrying wheels, millimetres	0	0	0	0	0	0	850
Class of motor	Direct-current series.	Direct-current series.	Direct-current series.	Three-phase induction.	Alternating-current series.	Direct-current series.	Direct-current series.
Voltage of motors, volts.	400	375	750	750	200	600	550
Motor periodicity	0	0	0	40	20	0	0
Hour rating, horse-power per motor	100	45	75	60	40	125	150
Number of motors.	4	4	4	4	4	4	2
Method of drive of motors.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothe gears.
Gear ratio	1 : 4	1 : 4·87	1 : 4·3-1 : 4·6	1 : 3	1 : 5·15	1 : 3·08	...
Motor control	Direct rheostatic control.	Direct rheostatic control.	Direct rheostatic control.	Resistance in rotor.	Voltage regulation at main transformer.	Resistance and multiple control.	Sprague resistan and multipl control
Normal tractive effort at wheel periphery, per car, kilograms	5,000	1,400	2,400	1,800	1,400	3,200	1,800
Normal speed of cars, kilometres per hour.	21	34	34	36	30	42	45
Maximum speed of cars, kilometres per hour.	55	45	45	36	45	70	60
Current-collecting device	Sliding shoe.	Bow.	Bow.	Bow.	Bow and rod.	Sliding shoe.	Sliding sh
Number and output of main transformers, kilovolt-amperes.	0	0	0	0	2 × 90	0	0
Brake system, besides electric	Screw.	Vacuum.	Vacuum.	Compressed air and screw.	Compressed air.	...	Compres air.
Passenger capacity per car.	48-56 and baggage	40-48	38-56	66	44	32	27 and bagg

r cars in use. **Table 4.**

illes.	*Lancashire & Yorkshire Railway.*		*North Eastern Railway.*	*Midland Railway.*		*Milan-Varese-Porto Ceresio.*			*Valtelina.*
r with motors.	Light.	Heavy.		Siemens.	Westing-house.	Car with four motors.	Car with four motors.	Car with two motors.	
2	24	40	62	2	1	20	5	16	10
4	4	4	4	4	4	4	4	4	4
4	4	2	2	2	2	4	4	2	2 (+ 2)
Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
30	46	22	29·8-30·3	41·5	37·5	41	53	45	53
11	17	7	6·3	19	15	12	12	6·5	23
	19·3	...	17·5	18·3	18·3	18·29	19·36	19·36	19·14
	14·7	...	14·25	...	...	13·2-14·7	15·5	15·5	14·0
1 bogie.	12·3	...	12·15	...	...	11·0-12·5	13·0	13·0	11·5
	2·4	...	2·1	2·6	2·6	2·2	2·5	2·5	2·5
1,067	1,067	...	920	1,100	1,100	1,040	1,040	1,040	1,170
0	0	...	920	1,100	1,100	0	0	1,040	0 (1,170)
irect-rrent eries.	Direct-current series.	Direct-current series.	Direct-current series.	Alternating-current series.	Alternating-current series	Direct-current series.	Direct-current series.	Direct-current series.	Three-phase induction.
550	600	600	550	300	300	650	650	650	3,000
0	0	0	0	25	25	0	0	0	15
80	150	125	150	200	150	150	150	150	(75) Mean.
4	4	2	2	2	2	4	4	2	2 (+ 2)
oothed ears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Toothed gears.	Axle motor.
...	1 : 1·95	1 : 2·15	1 : 3.24	1 : 3 (?)	1 : 3 (?)	1 : 2·5	1 : 2·5	1 : 2·5	1 : 1
omson, istance and ultiple ntrol.	Direct rheostatic control.	Resistance and multiple control.	Resistance and multiple control.	Voltage regulation at main trans-former.	Voltage regulation at main trans-former.	Resistance and multiple control.	Resistance and multiple control.	Resistance and multiple control.	Cascade coupling and rotor resistance.
,900	5,000	2,100	1,600	3,300	2,500	3,800	3,800	1,900	2,000 and 1,260
45	32	32	50	32	32	43	43	43	32 and 64.
60	100	100	75	80	80	90	90	90	64
ng shoe.	Sliding shoe.	Sliding shoe.	Sliding shoe.	Bow.	Bow.	Sliding shoe.	Sliding shoe.	Sliding shoe.	Bow.
0	0	0	0	1 × 200	1 × 200	0	0	0	0
pressed air.	Vacuum.	Vacuum.	Com pressed air.	Vacuum.	Vacuum.	Compressed air.	Compressed air.	Compressed air.	Compressed air.
...	69	70	64 or 44 with baggage.	72	72	73	40 and baggage.	76-80	56 or 24 (saloon)

*

Table 5. Particul

Name of railway	*Freiburg-Murten-Ins.*	*Montreux-Bernese Oberland.*	*Burgdorf-Thun.*	*Simplon Tunnel.*	*Seebach-Wettingen.*	*Locarno-Va Maggia.*
Classes of trains handled . .	Passenger trains. Goods trains.	Express trains. Passenger trains. Goods trains.	Passenger trains. Goods trains.	Express trains. Passenger trains. Goods trains.	Passenger trains. Goods trains.	Passenger tra Goods train
Means for operating express trains.	...	Rail motor cars.	...	Locomotives.	...	...
Means for operating ordinary passenger trains.	Rail motor cars.	Rail motor cars.	Rail motor car.	Locomotives.	Locomotives.	Rail motor ca
Means for operating goods trains.	Rail motor cars.	Rail motor cars.	Locomotives.	Locomotives.	Locomotives.	Rail motor ca
Number and kind of trailers	6 passenger carriages. 50 goods wagons.	30 passenger carriages. 115 goods wagons	10 passenger carriages. 67 goods wagons	Trailers for passengers and goods not in specific numbers, in common with other lines.	Trailers for passengers and goods not in specific numbers, in common with other lines.	2 passenge carriages. 16 goods wag
Train weight of express trains, tons.	...	46-85 2 × (46-85)	...	300	...	...
Train weight of passenger trains, tons.	70-80	46-85 2 × (46-85)	90	300	100	38
Train weight of goods trains, tons.	70-80	...	100-150	400 (600)	150	35
Speed of express trains, kilometres per hour.	...	16-27	...	70 (Maximum.)	...	...
Speed of passenger trains, kilometres per hour.	20	10-15	36	70 (Maximum.)	40 (Maximum.)	21-25
Speed of goods trains, kilometres per hour.	20	10-15	18	35 (Maximum.)	40 (Maximum.)	21-25
Actual maximum starting acceleration, metres per second per second.	0·15-0·20	...	...	...	0·1-0·2	...
Total number of trains per day.	10·7	19·7	16·8 passenger trains. 4·7 goods trains.	11 passenger trains. 5 mixed trains.	14	14
Particulars of traffic hauled, train-kilometres and ton-kilometres.	In 1906 : 189,900 train-kilometres; 11,991,000 ton-kilometres.	In 1906 : 383,400 train-kilometres; 20,715,000 ton-kilometres.	In 1906 : 306,000 train-kilometres; 20,353,000 ton-kilometres.	From 1 June 1908 to 31 May 1909 : 145,500 train-kilometres; 22,933,000 ton-kilometres, or 32,458,000 including locomotives.	From 1 December 1907 to 3 July 1909; 129,710 train-kilometres, 16,705,000 ton-kilometres, locomotives included.	...
Particulars of electrical energy consumed, kilowatt-hours at power station.	...	...	...	From 1 June 1908 to 31 May 1909 : 1,339,000.	From 1 December 1907 to 3 July 1909: 510,731.	March 190 24,415.
Consumption in watt-hours at power station, per ton-kilometre (when marked with an asterisk, at contact line).	33·7*	124	68	37	32·2	52-53

ne traffic **Table 5.**

ris-Orléans.	*Paris-Versailles.*	*Lancashire & Yorkshire Railway.*	*North Eastern Railway.*	*Midland Railway.*	*Milan-Varese-Porto Ceresio.*	*Valtellina.*
press trains senger trains.	Express trains. Passenger trains.	Express trains. Passenger trains.	Express trains. Passenger trains. Goods trains.	Passenger trains.	Express trains. Passenger trains. Goods trains.	Express trains. Passenger trains. Goods trains.
ocomotives.	Locomotives.	Rail motor cars.	Rail motor cars.	...	Rail motor cars.	Rail motor cars and locomotives.
l motor cars locomotives.	Rail motor cars and locomotives.	Rail motor cars.	Rail motor cars.	Rail motor cars.	Rail motor cars.	Rail motor cars and locomotives.
n locomotives.	...	...	Electric and also steam locomotives.	...	Electric and also steam locomotives.	Locomotives.
lers for passgers and goods in specific nbers, in comn with other es.	Trailers for passengers and goods not in specific numbers, in common with other lines.	Trailers for passengers and goods not in specific numbers, in common with other lines.	Trailers for passengers and goods not in specific numbers, in common with other lines.	Trailers for passengers and goods not in specific numbers, in common with other lines.	80 passenger carriages, 12 luggage vans, goods wagons in common with other lines.	Trailers for passengers and goods not in specific numbers, in common with other lines.
400 Maximum.)	150	170 (Maximum.)	240	...	110	140 with rail motor cars. 240 with locomotives.
200 Maximum.)	200	150 (Maximum.)	240	190 (Maximum.)	110	140 with rail motor cars. 240 with locomotives.
...	...	...	300 (Quay line).	...	135	370
70 Maximum.)	60	90	73	...	90	64
70 Maximum.)	40	56	52	32	60	64
...	...	...	23	...	40	32
...	...	0·7-1·0	0·45	0·25	...	...
...	...	...	...	...	60-70 rail motor cars trains.	30-35 for passengers, 6-10 for goods.
1904 : 521,000 in-kilometres, 156,000 ton-kilometres.	In 1905 : 453,200 train-kilometres, 59,900,000 ton-kilometres.	Per year: 2,400,000 train-kilometres, 296,000,000 ton-kilometres.	Per year about 195,000 train-kilometres by the rail motor cars.	...	Per year about 135,000,000 ton-kilometres by the rail motor car trains.	Per year about 67,500,000 ton-kilometres by the passenger trains and 31,600,000 ton-kilometres by the goods trains.
ear: 7,000,000.	In 1905 : 2,570,000 (at substations).	In 1908 : 26,230,400 for traction ; in addition 1,277,120 for light and power.	Per year about 9,000,000	Per year about 3,100,000	Per year : 6,200,000.	Per year : 5,600,000.
40 substation).	43 (at substation).	23* 50* (according to conditions).	48 (at substation).	35	45	59

SECTIONAL DISCUSSION

Meeting held on 11 July 1910 (morning).

MR. GERSTNER, IN THE CHAIR.

The President. (In French.) — As Mr. Gibbs, reporter for America, is absent, I request Mr. Crawford kindly to give us a summary of his report.

Mr. Crawford, Pennsylvania Lines West of Pittsburgh. — The following remarks will perhaps bring the question briefly before the Congress :

Introduction. — It should be noted that the scope of the paper is confined to American practice for heavy electric traction under steam railroad conditions, and does not cover trolly systems or single car operation.

Historical reference. — It should be noted from brief reference to the history of electric traction in America, in the paper, that nearly all the work covered by the report is for very heavy service and much of it at high speed.

Systems. — It should be noted that the longest development has been with systems employing direct current motors and for the *use of third rail* rather than overhead conductors; experience with alternating-current motors has been more limited, but there are now a number of installations of this character which will enable comparative operating results to be known shortly.

Operating methods. — It should be noted that electric locomotive operation is generally confined to short distance haulage in terminals or in tunnels; for long distance haulage and suburban service, trains having motors on the cars and operated by the multiple unit control is almost universally used.

Character of equipment. — Under this heading, the report gives summary of experience with the different main sections of electrification work, from the power house to the motors on the cars. American practice tends to the elimination of complication and toward ruggedness in apparatus throughout in order to eliminate as far as possible expert attendance. Electric locomotive development is referred to at some length, and it is important to note that for high speed work the characteristics of steam locomotives in distribution of running gear, wheel arrangement, and height of centre of gravity, is considered of great importance. It is considered that electric locomotives are still suscep-

tible of considerable development both in type and detail.

First cost. — Reference is made to the very high first cost of electric installations deterring the rapid introduction of electricity for main line work. Also, that rapid development of apparatus makes it desirable to go slow in the introduction of electric traction generally.

Cost of operation. — Rather complete figures are given for operating costs on two large systems and these have been compiled over a sufficient length of time to constitute fairly reliable comparison with steam operating costs for the same character of service. Figures, however, are still too meagre for generalization, and analysis of operating costs should be made for the present with full knowledge of local conditions and by experts skilled in not only electric apparatus, but in railway operation.

Cost compared with steam. — It will be noted that almost invariably a saving in actual operating costs may be predicted for electric operation over that of similar service operated by steam, but that it takes quite a dense service to enable the operating savings to pay interest on the added first cost of electric equipment on an existing line. This, however, should not be considered the only advantage of electric operation inasmuch as the collateral advantages in many cases may be controlling; such as,

a) Inceased capacity of the lines;

b) Elimination of smoke and gases from the locomotives;

c) Increased average speed in service with frequent stops;

d) Increased business resulting from the above advantages.

The President. (In German.) — I request Mr. Gleichmann, reporter for Germany, to give a summary of his report.

Mr. Gleichmann, *reporter.* (In German.) — My report deals with the doings of the German railway administrations in connection with electric traction.

I. *Preliminary investigations.* — Among the German railway administrations, those of the Prussian-Hessian, the Baden and the Bavarian State railways have examined more closely the question whether and under what conditions electric traction can advantageously replace steam traction on main-line railways. As regards the historical part of the subject, I can briefly summarize it and refer to my report. It may be mentioned that the *administration of the Prussian State Railway* has contributed much towards the elucidation of doubtful points involved by operating experimental services, on the Wannsee line with direct current, and on the Spindlersfelde line with single-phase current. On the other hand, this administration has, as we know, taken a very important part in high-speed trials with three-phase current.

As of particular importance, we may mention the adoption of electric traction on the suburban line Ohlsdorf-Hamburg-Altona-Blankenese, which is repeatedly referred to in my report. This important service, operated by means of eighty-six double automotor cars, works smoothly. Since the adoption of electric traction using single-phase current, the traffic on this line has been increasing considerably.

The administration of the Baden State Railway has examined the question of electric traction on its lines in a memoir

dated 1906, investigating in particular the conditions on the Wiesental line which, owing to its traffic and its profile, is peculiarly suitable for electric traction.

The administration of the Bavarian State Railway submitted in April 1908 to the Landtag a memoir dealing with the adoption of electric traction on its lines. In this memoir, the consumption of energy on the whole railway system is determined in order to ascertain to what extent the water-powers available are able to supply the electric energy required for railway traction. The memoir compares the properties of the different forms of current and investigates the important and decisive question of the economy of electric traction. Besides this general investigation, special attention is paid to certain lines for which electric traction has in the first place been proposed. Mr. Jacqmin, engineer of the Belgian State Railway, has published in the *Bulletin of the Railway Congress* for January 1910, long extracts from this memoir.

II. *Objects of the electrification and new projects.* — 1. *The administration of the Prussian State Railway* has proceeded to electrify the suburban lines Berlin-Grosslichterfelde and Hamburg-Altona in order to increase the number of trains, to make it possible to vary the composition of the trains in accordance with the density of the traffic, so as to reduce working expenses, and finally, in order to reduce the time required for the journey, by accelerating the starting and the running of the trains. The elimination of smoke and the resulting cleanliness have also been taken into consideration. In addition, the administration of the Prussian State Railway is also going to use electric traction on the main line Magdeburg-Halle-Leipzig, beginning with the Dessau-Bitterfeld section, in order to utilize the fuel of mediocre quality, of which there are deposits near the line, by burning it on the spot.

2. *The administration of the Baden State Railway* electrified the Wiesental line, in order to utilize the cheap water-power available, from the Augst-Wyhlen works, on the Rhine.

3. *The administration of the Bavarian State Railway*, for operating the Salzburg-Reichenhall-Berchtesgaden line, utilizes a favourably-placed water-power, eminently suitable for meeting variations in the load; this power station will in addition supply lighting current and power current for other purposes.

The works for these three lines are now being built.

Moreover, the administration of the Bavarian State Railway proposes to utilize the 200-metre (656-foot) fall between the Walchensee and the Kochelsee. This water-power is eminently suitable for railway traction owing to its great capacity of accumulation. It is in the first place going to be utilized for operating the lines running from Munich to the mountains. In addition it is to supply lighting current and power current for other purposes.

The results obtained with electric traction on the lines mentioned will make it possible to ascertain whether the German railways should extend the electrification of their lines.

III. *Selection of current for main lines.* — This question is of exceptional importance, not only from the point of view of the motors of the cars or of the locomotives, but also from that of the transmissions

and of the power station. It requires careful consideration, for any subsequent alterations are extremely difficult and costly. It is not possible to select for each section the most economic kind of current, as determined by calculation; *on the contrary, one must consider all the lines, or the whole railway system,* in order to determine the kind of current universally utilizable from the points of view of economic operation and economic utilization of the vehicles. It would take too long now to enumerate the advantages and the disadvantages of the different kinds of current. I may be allowed to refer you to the summary table in the Bavarian memoir, published in the *Bulletin of the Railway Congress* for January 1910.

The three German railway administrations mentioned above decided, after thorough inquiry, to use single-phase current generated at the station at a sufficiently high voltage and with 10,000 volts in the contact line. This makes it necessary for the water-power stations to have accumulators. This system has been recognized to be more economic, in the majority of cases, than electric compensation of the maximum loads.

This decision had as basis :

1° The simple and economic transmission of the energy from the power station to the overhead conductor without complicated intermediate appliances, as required in the rotary-current to continuous-current system;

2° The overhead conductor which as a *single-pole* system can be arranged to suit the needs of the main-railway traffic for higher voltages, and is materially cheaper to construct and work and above all is safer than in the case of rotary-current. More especially is the arrangement at switches simpler;

3° The complete adaptability of the rotary-current motor to the needs of main-railway traffic : speed varying with the train load, greater tractive power when starting, and most independence of a voltage drop (see figs. 34 and 35).

These three points include at the same time the requirements which have always been considered necessary by the German State railway administrations in the case of electric are operation.

The chief disadvantages of rotary-current working are as follows :

1° Alternating-current requires a commutator like the continuous-current motor, while the rotary-current motor only requires collector rings (cascade or resistance connections) or can also be constructed like the Simplon machine with armature short-circuit (changing of pole connections);

2° The alternating-current motor must be constructed for low voltages, and hence requires a transformer to reduce the voltage from that in the conductor to that suitable for the motor. This at the same time serves for regulating the voltage. This transformer produces a loss, if only a slight one, and increases the weight of the car. This increase in weight necessitates the consumption of more energy;

3° The single-phase motor cannot directly utilize the potential energy liberated in running downhill, so as to reduce the load at the power station and diminish the varations in the load, while the three-phase motor can very easily be used as a generator on a sufficiently steep down-gradient.

As regards point 1, it has to be noted

that the single phase motor is less simple than the three-phase motor, but that, like the direct-current motor, it can be designed to meet all the technical conditions of railway service.

As regards point 2, the weight of the locomotive is greater. But the extra cost of electric energy, caused by the design of the single-phase locomotive, may be more than counterbalanced by the material reduction in the losses of a railway operated with single-phase current. I beg to refer you to the note at the bottom of page 67 of my report (1). This is due to the fact that with the single-pole line for single phase current it is possible to use, with the same degree of safety, a considerably higher voltage than with the two-pole line for three-phase current, and that the losses are inversely proportional to the square of the voltage. It must however not be forgotten that the contact line for single-phase current only requires half as much copper as that for three-phase current.

As regards point 3, the possibility of very simply recovering energy when running downhill is an undisputed advantage of the three phase motor. It is especially on long down-gradients in the case of slow goods trains that considerable quantities of energy can be recovered. Now it is necessary to ascertain the importance of this recovery, especially in the case of a railway system where most of the lines are not of this kind. The energy recoverable on the system of the Bavarian State Railway is calculated very accurately in the memoir mentioned. Mr. Jacqmin reproduces the figures obtained in his note on this memoir (p. 480). The recovery is 2·49 per cent in the case of the goods service and 1·14 per cent in that of the passenger service; the mean is 1·85 per cent. It is not large enough to exercise a preponderating influence on the selection of the kind of current, all the more so as the more economic construction of a single-phase line and the greater distances between the transformer substations are an offset on the other side.

It must not be forgotten, when it is a question of recovering energy, that the motors become larger and the line must not be interrupted, otherwise trains may easily attain a dangerous speed.

Another important question is the frequency of the single-phase current.

The administrations of the German railways will adopt from 15 to 16 $^2/_3$ periods, because this frequency is the most advantageous without materially affecting the cost of the generators and the transformers. I beg to refer you to the details given in my report.

IV. *Comparative net cost.* — Subject VIII includes the comparison of the cost of the three kinds of current : direct, one-phase and three-phase.

In my report, I give some instances applying to short lines. They show the lowest figures in the case of single-phase current. But they cannot for the moment be considered decisive arguments.

The German administrations have made no comparative calculations for their lines. Moreover, it is very difficult to make such calculation with any accuracy, for one must obtain prices for installations which one does not think of building. On the other hand, there are many advantages and

(1) Vide *Bulletin of the Railway Congress*, number of March 1910, p. 1079.

disadvantages which cannot be expressed in figures and which nevertheless, for technical working reasons, can lead to giving the preference to such and such a kind of current.

I will only mention, in this connection, the simple and easy installation of the single-phase mains and the economical speed regulation of the single-phase motor.

The administration of the Bavarian State Railway has compared the cost of steam traction and of electric traction with single-phase current by calculating, on the one hand, the cost of steam traction, on the other, that of electric traction, not including the cost resulting from the consumption of energy. The difference represents the maximum the expenditure mentioned can reach. If the power station can supply energy at the unit price so determined, electric traction is not more expensive than steam traction.

If it can be supplied at lower prices, electric traction gives corresponding financial advantages. Such is the case with a certain number of lines with busy traffic.

Another method consists in assuming the cost per kilowatt-hour to be known, and in calculating the minimum consumption of energy required to justify the change from the economic point of view: this is called the *critical consumption*. This consumption corresponds to the minimum amount of traffic required for the economic success of the electric operation.

This method was adopted in order to obtain a general view as to the possibility of extending electric operation to the whole Bavarian State Railway system.

Detailed information about this point is given in the *Bulletin of the Railway Congress* for January 1910.

V. — An important question is also that of the most important elements of the electric-traction equipment of main lines, namely *the conducting lines and the motor vehicles*.

With single-phase current, only an overhead line can be used.

The general opinion is that the contact wire must be freely suspended from a wire rope. It must be grooved, so that it can be clipped. Soldering must be avoided, as this would affect the resistance. The wire rope must be made of material not attacked by smoke. Silicon bronze is suitable for this purpose. The Monnot metal has now for some time been recommended; this is steel wire covered with a durable layer of copper.

The overhead wire should be placed high up, at a height of about 6 metres (19 ft. 8 in.) above rail-level, so that the crews of steam locomotives may not run any danger in using their tools. Provision has to be made that steam locomotives may still be used on the lines.

The poles must be made of iron, so that they always retain the necessary strength. Double insulation is necessary and great care must be devoted to it. Fuller details are given in the report.

Particular care is also necessary, and considerable expense must also be incurred, for eliminating any influence of the single-phase line on the telegraph, telephone and signal lines. The Swiss post and railway administration, and the *Oerlikon Works* have made important experiments, described in the report, which show how this problem can be solved.

The *motor vehicles* used can be automotor cars or locomotives.

The equipment of the automotor cars presents no specially new features when gearing is used.

Locomotives have passed through a special evolution. In order to ensure their stability on curves, the motors are placed very high so as to be readily accessible. In this way, the greatest possible fraction of the total weight of the locomotive is suspended on springs; this has a considerable influence on the state of the track.

A separate shaft is interposed between the motors and the driving axles, with which the driving axles and the shafts of the motors are connected by rods. Experiments made with such intermediate shafts have not yet led to any conclusive results.

Since my report was completed, in August 1909, and not counting two locomotives for the experimental Oranienburg line of the Prussian State Railway, altogether thirty-five single-phase locomotives have been definitely ordered, for passenger and goods trains, from German firms; namely six for the Prussian State, fifteen for the Swedish State, twelve for the Baden State, one for the French Midi, and one for the Lötschberg.

All these locomotives are designed on the lines which have been indicated. Some of the types are shown in my report. The motors give a continuous output of up to 1,100 horse-power. Generally there are two of them. The Prussian State Railway, however, is only having one motor fitted to the locomotives which are going to be used on the Dessau-Bitterfeld line; this makes their construction cheaper and simpler.

As a rule, for driving motor vehicles, a system of control by contacts is used, which can easily be operated from the two ends of the car.

Before concluding this summary I should like to remark that all the reports submitted to the Congress, on subject VIII, agree entirely as regards the most essential points. This may be considered a proof that ideas in connection with electric traction are beginning to become settled. Electro-technical science now enables us to foresee that practical applications can be tried with every chance of success. Now that profound theoretical investigations have been made, further progress and results will only be obtained by practical trials.

I will sum up my report in the following *conclusions* :

1° From the technical point of view, the adoption of electric traction on main lines is possible; one can use either automotor cars, or locomotives for heavy trains and high speeds;

2° With the conditions which apply in the case of the German administrations : utilization of suitable water-powers more particularly in the south, and of fuel in the north, single-phase current represents, in the present state of science, the kind of current most suitable for the needs of main lines. This current presents the following advantages :

a) Very simple installation of the conducting line;

b) Motor vehicles the speed of which can be economically regulated within wide limits;

c) Minimum capital outlay;

d) Maximum economy;

3° A frequency of 15 to 16 $^2/_3$ periods may be considered as most suitable in the case of single-phase current; a line voltage of 10,000 volts is suitable and high enough;

4° The possibility of recovering electric energy is not of paramount importance, taking the German railway conditions into consideration, in the question of choice of kind of current. Nevertheless this point must be taken into consideration in the future evolution of the motor stock in order to make it possible to realize, on lines with long steep gradients, the advantages resulting from such recovery, namely lightening the load on the power station and improving the action of the brakes on the vehicles.

The President. (In German.) — I call upon Mr. Hruschka, reporter for Austria and Hungary.

Mr. Hruschka, *reporter.* (In German.) — I have tried, in my report, to give as complete an account as possible of the state of electric traction of trains in Austria and in Hungary, dividing the lines concerned into three groups : lines in operation, lines under construction, lines projected and studied. I would here remark that by large railroads I mean all railways of a more or less considerable length.

I. *Lines in operation.* — Austria and Hungary only have 300 kilometres (186 miles) of lines electrically operated ; and these are only local and secondary lines. I will only mention two : Vienna-Baden and Trente-Malè. The Vienna-Baden line is an interurban railway 30 kilometres (18 6 miles) long. The passenger service is worked by means of electric automotor cars following each other in quick succession, and the rather busy goods service is worked with steam locomotives. A characteristic feature of the line is that it uses, in the suburbs of the towns, the tramway lines, using 550-volt direct current. The service has been materially improved, firstly by the electrification itself, which has made it possible to increase the number of trains to ninety-six per day, and more especially by extending the railway right into the towns of Vienna and Baden, an extension hardly possible except with electric traction. In the first year after this alteration had been made, the traffic grew to such an extent that the receipts increased by 180 per cent. It will be of interest to add that the working coefficient in the case of electric traction fell to 68 per cent as regards passenger traffic, while in the case of the goods service, which is generally more lucrative, it remained stationary at 84 per cent.

The second line, Trente to Malè, is an interurban metre (3 ft. 3 $^3/_8$ in.) -gauge line, 60 kilometres (37·3 miles) long, in the south of Tyrol. It has been working too short a time to make it possible to give any detailed information about it. I will only remark that the preliminary calculations showed that steam traction would have been materially more costly than electric traction in the case of this line, which has gradients of 53 per mil.

II. *Lines under construction.* — I am pleased to be able to state that electric traction will be started this year on two large railways. In the first place there is the secondary standard-gauge line, 50 kilometres (31 miles) long, from Vaez over Usp to Gödöllö, in the neighbourhood of Budapest, which will relieve the capital by operating an important goods traffic. This will be the first railway in the kingdom operated by single-phase current, 16 $^2/_3$ periods, definitely selected. The second line is the Alpine line of Lower Austria, from St. Polten to Mariazell ; this

has a gauge of 76 centimetres (2 ft. 6 in.) and is 90 kilometres (56 miles) in length. It is distinguished by the exceptional high power of the locomotives, 550 horse-power, gauge 76 centimetres (2 ft. 6 in.).

Taking it altogether, there are twenty-one electric locomotives in use in Hungary, all for single-phase high-voltage current.

III. *Lines projected and studied.* — The lines which we are going to mention form, after all, only a modest beginning for such a large empire, so richly gifted with water-powers. On the other hand, it should be noted how extensive the studies made are, and they will probably result in less than a year in rather important works. The administrations we are considering in this connection are firstly, that of the Austrian State Railway, then, to a minor extend, that of the Austrian Southern Railway and that of the Hungarian State. All these administrations are unanimously of the opinion that the electrification of a long enough line, with busy traffic, and presenting every possible difficulty, is the only true means for demonstrating the technical and economical advantages of electric traction in a tangible and numerically accurate form.

The Austrian railway ministry recognized the importance of these questions many years ago, and some years ago started a number of investigations so as to solve certain of the problems involved. In the first place there are general investigations for establishing the technical principles applying to such services or to their modifications.

Then also the general economic principles will have to be worked out, the consumption of energy for the whole system (19,000 kilometres [11,800 miles] in length) will have to be determined, and general rules laid down for the projects.

Then there is a second group consisting of special work such as drawing up accurate estimates, technical projects, and comparisons of the working expenses of a certain number of given lines. The lines in question are the Arlberg, Innsbruck-Lindau, Bozen-Meran and all the State lines starting from Triest, the Tauern, the Karawanken and the Wochein lines, and finally, a certain number of local and secondary lines in Upper Austria.

Besides economical and technical researches a detailed analysis is also made of all the particulars of all the Austrian water-powers of more than 1,500 horse-power. A special department is appointed for dealing with the legal and administrative questions which arise in connection with these investigations.

There are two reasons for electrifying the lines of the Austrian State Railway. Generally speaking, and particularly as regards districts of a certain size, economic considerations, reduced expenses as compared with steam traction, are the most important; in some cases, however, one desires to obtain certain technical advantages, outside or even in spite of economic considerations. Among such advantages we may mention the elimination of smoke and gases, which at times and in places seriously inconvenience the employees on goods trains in single-track tunnels, where there are curves and steep gradients; moreover, on the same lines, there is the possibility of materially increasing, when electric traction is adopted, the density of

the traffic, up to the limits compatible with the technical conditions of working. It may thus be possible to avoid the great cost of doubling the track, of building parrallel tracks, of making level passing places on steep gradients, of strengthening bridges, etc. Economy, which is the chief factor in these cases, is generally ensured on large railways if the cost of current is sufficiently low or the cost of coal is sufficiently high, or if the traffic is sufficiently dense. In this connection I would emphasize that these three factors, according to my own experience and to that of all the experts I am acquainted with, vary so much at different points of a large system that no general opinion can be given as to the economy over the whole, but that each individual case must be examined, from line to line, on its own merits.

The critical cost of the current which Dr. Gleichmann has mentioned to us, that is the maximum price beyond which electric traction becomes the more costly, varies between some fraction of a centime and several centimes par kilowatt-hour. Prices of this kind can be obtained with water-power installations, and here again it must be stated that in our country water-powers are comparatively dear, so that current can be obtained at low rates only if the supply of traction current is combined with the more profitable supply of current for industrial purposes. I will mention that in Upper Austria a contract for the supply of several thousands of horse-power has been made between a given electric undertaking and the administration of the Austrian State Railway, at the rate of 1·5 centimes (0·144*d.*) per kilowatt-hour, and that for a maximum consumption of up to five times the mean for the year. In certain cases, good economic results can be obtained with internal-combustion motors. But for the time being, these are exceptional cases.

The Austrian Southern Railway Company has also started calculations for its system, for about 1,500 kilometres (930 miles), and intends to proceed to electrify a rather long line, probably in the Tyrol or in Carinthia. The Hungarian State Railway is considering the case of a line with steep gradients, starting from Fiume and ending at Morawicza.

I now pass to another point, the most important of all, the kind of current. By that I mean the whole arrangement, including the voltage and the frequency. There are no official data about these points. I will only express my own personal opinion that the Austrian State Railway will use single-phase current, $16^2/_3$ periods and 10,000 volts on the line. The Austrian Southern Railway Company, in the answers to my list of questions, gives the preference to three-phase current, chiefly on account of the possibility of recovering current on down gradients. The Hungarian State Railway has not given any opinion. The most important reason why we do not choose three-phase current is that this makes it necessary to have two conductors of different polarity. The principal reason why we do not choose direct current is the high initial cost. Single-phase current has these advantages: 1° simplicity and low cost of mains and of substations; 2° ease of speed regulation; 3° possibility of using automotor cars of very different types in one and the same train; 4° lower prime cost and lower working expenses. A voltage of 10,000 volts

in the contact line is no doubt sufficient from the economical point of view, and on the other hand it is not excessive, owing to the severe climate of our Alps and to the numerous tunnels. As regards the frequency, which in our opinion should be round about 15, we have selected $16^2/_3$ chiefly because this is one third of 50 and because the possibility of obtaining, both under normal conditions and in exceptional cases, current from existing private power stations, will be a material advantage in connection with this system of current.

I have mentioned in my report several points which are of importance in the design of locomotives and which are nearly generally recognized as correct, as all modern builders have accepted them : 1° the importance of raising the centre of gravity of the locomotive ; 2° the use of carrying axles in the case of high speeds, particularly in the case of rails of lighter cross-section ; 3° the elimination, as far as possible, of gear wheels on large locomotives (opinions are still divided as regards this point).

I do not think that one really uniform system of current and one single kind of current will be adopted for the whole of Europe. I will enunciate three principles, of an international character, well within the scope of the activities of our Cogress :

1° The choice of the kind of current must not be left to the builders, for it will then be affected by matters of chance, sometimes also by interested points of view. On the contrary, that choice must be made by the railway administration itself, after a careful examination of all the really important terms of comparison;

2° The administrations should select, for the minor lines, a kind of current which is as favourable from the technical and economical point of view, for large railways ; it should in no case allow itself to depart from this principle owing to special peculiarities of these lines, such as supply of energy by given power stations, previously-made estimates, and other local circumstances ;

3° It is advisable, by agreement between the different administrations, to set up not one single standard, but several normal cases, as few as possible, between which the different administrations can choose, so that, taking it altogether, the different current systems should not vary too much on the Continent.

The following are the conclusions to be drawn from my report :

1° In Austria and Hungary, 170 kilometres (105 miles) of railway are electrically operated; the work quite satisfactorily. At present 150 kilometres (93 miles) of lines are being constructed, to be operated with high-voltage single phase current. The administration of the Austrian State Railway is considering the electrification of its system, altogether 19,000 kilometres (11,800 miles) of line, and the Austrian Southern Railway, that of its Austrian system of 1 500 kilometres (930 miles); moreover, detailed projects have been made for 1,000 kilometres (620 miles) of the States lines and contracts have been made for ensuring the possession of the water-powers required for a long time to come;

2° Beyond doubt the electrification of certain lines (particularly if water-power is used for the current) will at once result in important economies, and also in an increase of speed and in the elimination of the disadvantages of smoke. Moreover, it gives the possibility, very important in a mountainous country with busy lines, of dealing with a

maximum of traffic before it becomes necessary to build new lines; and that without increasing the axle-load and strengthening the bridges;

3° When traffic increases, it will be possible to electrify all steam railways economically; a future retrogression is hence not to be feared;

4° The best current for all lines of a certain length appears to be, in the present state of knowledge, single-phase current with 16 2/3 periods per second, and (in the case of Alpine lines with many tunnels) with a voltage of about 10,000 volts;

5° The administrations should only select the kind of current after consideration of its adaptability to large railway systems and attempts should be made (perhaps with the assistance of the international railway congresses) to set up a few standard cases, from which the administrations can make a selection.

The President. (In German.) — I request Mr. Wyssling, reporter for all countries except America, Germany, Austria and Hungary, to give a summary of his report.

Mr. Wyssling, *reporter.* (In German.) — Gentlemen, I will begin by thanking the Swiss Federal Railway and the Permanent Commission of the Congress for giving me the opportunity, although I do not belong to any of the administrations which are represented here, of attending your interesting discussions and collecting information there.

In my report, which has been printed and distributed to the members of the Congress, I have set forth the reasons why this report concerns Switzerland, above all. I have received two answers from French railways, two from Italian railways and three from English railways; and certain of these answers have given me very detailed information which I highly value. Nevertheless I have not considered the data available sufficient to give me the right to form any definite opinion as to the question of the best systems for those countries. I have limited myself to giving a summary, in the tables in the third part of my report, of the information received. I have also explained in my report why I think that I can best contribute towards the solution of the problem by giving you the results obtained by the Swiss commission for the investigation of electric traction. That commission has very carefully examined the question of system and that of comparative cost. It has carried out its investigations with the co-operation of railways, electrical manufacturers, non-interested professional associations and several special collaborators, among whom I will name, as regards the question we are considering, Mr. L. Thormann and Dr. W. Kummer.

In Switzerland, there are economic conditions which lead to the adoption of electric traction. Seeing that all our operation is by means of steam locomotives heated with coal which we are obliged to obtain wholly from abroad, it is clear that we must try to utilize the water-powers which we have in our country. That, besides the other well-known reasons, is with us the chief reason in favour of the electrification of the railways.

Subject VIII includes the question of system and of cost. As regards the technical comparison of the systems, it must, in order to be useful, assume as basis definite conditions, and consequently definite voltages. That we have done in our investigations, taking as bases the following hypotheses :

1° Direct-current traction with third rail

and 800 volts, or with overhead line and 3,000 volts (motors with two collectors);

2° Three-phase current traction with 5,000 or 8,000 volts on two-pole overhead line;

3° Single-phase current traction with 15,000 volts on the contact line. We have generally taken as bases systems applied in practice. The economy depends on the upper limit of the voltage, limit determined in the case of the direct-current overhead-line system by the characteristics of the motors, in that of third-rail system by the properties of the third rail, and in the three-phase and the single-phase systems, by the insulation of the overhead line.

It was a question of comparing the systems, in the first place, according to the more or less perfect manner in which they satisfied working conditions on railways from the point of view of traction. Those conditions are more particularly the following :

1° Production of sufficient power or of a sufficiently large tractive effort in the locomotives or automotor cars by the different motors;

2° Adaptation of the tractive effort and of the speed of the locomotives or automotor cars to the requirements of the time-table under all conditions of service;

3° Satisfactory starting conditions;

4° Possibility of multiple-unit traction, of using several automotor cars in one and the same train.

The possibility of building satisfactory motors, developing enough power or giving a sufficiently large torque or tractive effort is proved in practice as regards direct current of the voltages stated; this was proved already in 1895 by the locomotives of the Baltimore and Ohio, and is again proved by the more recent locomotives of the New York Central and Hudson River Railroad. As regards three-phase current, we may mention, in Switzerland itself, the Simplon locomotives which do very hard work; they are described in detail in my report and have large motors with a continuous output of 850 horse-power; the hour rating of each locomotive is 2×850 horse-power. In the single-phase system there is the difficulty, increasing with the size of the motors, of avoiding sparking at the commutator; in the most recent types, however, this problem is solved in a very satisfactory manner in the case of motors having rather large dimensions. We have a proof of this more particularly in the case of locomotives of Swiss construction, for instance the locomotives built by the Oerlikon Works (Swedish State Railway, locomotives for the Seebach-Wettingen line, opened four years ago, for the Wiesental line, the latter with 475-horse-power motors, the new Lötschberg locomotive, with single-phase motors of 1,000 horse-power, which you had the opportunity of seeing Tuesday last at Oerlikon).

As regards the more or less complete utilization of the adhesive weight by the tractive effort obtained with electric motors — and this is certainly a criterium of the power of the motors — it may be asserted that the different types of motors now all give a good utilization of the adhesive weight. I give, in a table in my report. a whole series of figures in this connection. These figures show that from this point of view electric locomotives are markedly superior to steam locomotives and that the new single-phase loco-

motives are but very slightly inferior to the direct-current and three-phase locomotives. At first, electric locomotives had some disadvantages; I will mention in particular the control and the defective suspension of the motors, the non-elastic suspension of too great a part of the weight, the too low position of the centre of gravity. These defects have been overcome, at least to a large extent, by new designs, the motors being fixed to the frame, and rods, shafts etc. being used. The descriptions of the electric Swiss locomotives show that already the earliest types, those of the Engelberg line and of the Burgdorf-Thun line (1898 and 1899), were arranged in this way. This point, I mean the mechanical arrangement of the driving of the axles by the motors, is that which, in electric locomotives, most requires improvement and experiment; but it is beyond doubt that a satisfactory solution will be found for all kinds of current.

The proper observance of the time-table is dependent on the following conditions:

a) Possibility of adjusting the speed and the tractive effort within wide limits;

b) Keeping within the same time, whatever the weight of the train;

c) It is also desirable that it should be possible to keep up on up-gradients the maximum speed compatible with the conditions of the line and authorized by law, in so far as a rational utilization of the motors, and above all the limitation of the power supplied by the power stations do not prevent this;

d) It should however be possible to attain, exceptionally, a great increase of speed without taking this into account, so as to make up for lost time.

In our opinion, it is advisable to avoid having complicated apparatus on the locomotive for regulating the speed and the tractive effort, such as frequency converters in the case of induction motors, or step-down devices in the case of direct-current motors, etc. In the case of direct current one is then limited to two or three normal speeds, obtained by coupling in series and in parallel; similarly in the case of the three-phase motor several different speeds can be obtained by changing the pole connections; these two methods are rational and have given satisfactory results. As regards pole connections, I would specially refer you to the new Simplon locomotive. As regards single-phase current, we know that the regulating transformer makes it possible to obtain any number of different speeds, without reducing the efficiency much; in the case of direct and of three-phase current this can only be obtained by regulation by means of resistances, and this is attended with considerable loss. The single-phase motor with its regulating transformer alone makes possible an exceptional increase of speed, beyond the normal limits, which, as I have already stated, is very desirable when making up for lost time; and this result can be obtained without having to make the motors extra large.

As regards starting, our experiments with the loads which have to be hauled in Switzerland show that it is advisable to have about twice the normal amount of power (hour rating). Up till now such accelerations have never been obtained with steam locomotives. We find that this is possible with all the three systems of motors without any abnormal increase

in the current of the motor or other disadvantage. The limitation of maximum torque given by the three-phase motor, which is a theoretical disadvantage of this motor, does not come into play in practice, and the difficulty of the commutation of the single-phase motor can now be considered as overcome in spite of the strong starting current, as long as a sufficiently low frequency is used, say 15 to 16 $^2/_3$ periods. Three-phase induction motors have the theoretical disadvantage, as regards multiple-unit traction, that they work together unequally, if there are any mechanical inequalities. On the Burgdorf-Thun line, however, this disadvantage appears to be negligible in practice.

The conditions which traction imposes on the motors from the technical point of view accordingly seem to us best satisfied by the single-phase system. It must however be admitted that in some respects the other systems are superior.

Other points of comparison are supplied by the examination — for the movement purely technical — of the economic advantages of the different systems, particularly as regards the following points : *a*) the dead weight of the rolling stock ; *b*) the efficiency and the specific consumption of energy; *c*) the recovery; *d*) the possibility of equalizing the load. We attach great importance to the last point on account of the utilization of water-powers.

The dead weight of the rolling stock, compared with the horse-power, or what is more correct, compared with unit torque or unit tractive effort, is given in the tables ; they show that, in the case of modern single-phase motors, it is about 10 per cent more than with the direct-current or the three-phase motor. But this extra weight adds only an insignificant fraction to the total load hauled. If we examine the table of efficiencies obtained, we find, it is true, that single-phase motors show 3 to 4 per cent less efficiency than the direct-current and three-phase motors, all other conditions being equal; but in considering this efficiency we must also consider the means of regulation. We there find losses of 14 and 13 per cent of the energy taken from the contact wire, absorbed in the regulating resistances necessary for obtaining the intermediate speeds, in the cases of three-phase and direct current respectively. The single-phase motor, which does not require such regulating devices, in this way more than makes up for the lower efficiency mentioned above.

The examples show that the efficiency of whole trains is about 10 per cent lower in the case of three-phase current and 5 per cent in that of single-phase current, than in that of direct current; but these figures depend largely on the conditions of the line and their influence is small as compared with the losses resulting with all the different systems from the permanent use of converters or of transformers at the feedings points. Those are the chief losses which occur with electric traction generally. The losses amount to from 40 to 55 per cent of the energy supplied by the power station on two railways operated by means of three-phase current on which old converters are used; but plates of special alloy have been introduced since and it should be noted that these figures no longer apply now ; in this direction, considerable progress has been made, for the use of these special alloys has made

it possible to reduce the above-mentioned losses to about one half. Taking it altogether, our calculations show that the efficiency of the whole installation is practically the same in the cases of direct and of single-phase current, and a little lower in that of three-phase current.

The variations in the power necessary at the driving wheels are characterized by the ratio between the maximum power developped at any given moment and the mean annual power. As this ratio depends much on the profile of the lines and on the time-table, we have determined it in the case of several of our projects, taking as provisional basis the time-table used with steam traction, and we have found that it varies between 6 and 3 in the case of systems with a traffic of $^1/_2$ to 30 million ton-kilometres (305,800 to 18,347,000 English ton-miles) per day. Later on, with a more suitable time-table for instance from all that part of the St. Gothard operated by a single central power station, we did not go below 3 in the case of unfavourable profiles. Taking 4 as mean, we have investigated the possible equalization of the loads on the different systems taking as basis the particulars of an imaginary system of suitable size. We have drawn up complete projects for balancing or equalizing plant and these investigations show that the equalization of the load by means of electric accumulator batteries involves a total cost which is less with single-phase than with three-phase current, and still less than with direct current.

These differences remain when the density of the traffic varies within wide limits. According to that density, the installations are more or less well utilized, so that the constant losses play a more or less important part; but with the greatest density of traffic considered, as well as the least, the differences remain of the same kind. This is chiefly due to the fact that in the case of high-voltage single-phase current a given railway system will require a smaller number of transformer substations and equalizing stations. But not only are fewer such stations required, but one can also use larger units which are of themselves more economic and which need a smaller staff. The difference is still more marked in the case of direct current. It is true that the single transformation required in the case of direct current involves less loss of energy; but the lower voltage in the contact wire makes it necessary to have a much greater number of substations when continuous current is used and also when three-phase current is used, so that the cost of transformation and the total cost of amortization show the ratio given above.

Our topographical conditions being such as they are, hydraulic accumulation can in many cases be adopted, when reservoirs can be established at a certain height, near the feed points. The value of this system depends entirely on the head and on the consumption of water when the turbines are running at no load. Few experimental results of this kind are available. Turbines of the ordinary kind, such as we have to consider, give rise to very great losses of water, and comparative trials have shown that with a fall of 200 metres (656 feet) hydraulic accumulation is still a little more expensive than equalizing batteries. But it is beyond doubt that with improved turbines, which can certainly be constructed, and with as

great heads as possible, hydraulic equalization of the loads will be cheaper than accumulator equalization.

Seeing the great cost of equalization, we asked ourselves whether it would not be more advantageous if all the fluctuations were dealt with by the power station direct, and to have no accumulation in the distributing system. It was found, in fact, that the most economic system was that of dealing with all fluctuations at the central station, provided that it worked with high-pressure water-power. I will give some figures which were obtained during this inquiry. The ratio of the annual expenses of the imaginary system, if all the fluctuations in the load are dealt with at the central station, to the annual expenses of a central station of mean power, with equalizing batteries in the system, is, other conditions being equal, as 100 to 180. According to circumstances, the second installation costs 25 to 80 per cent more than the first. The central power station dealing with the fluctuations would be much larger and more costly, as well as the installations for the distributing mains, but this exercices a great influence neither on the capital outlay nor on the working expenses; the same applies to the cost of the equalizing plant which becomes necessary in the other case.

We have also made calculations as to the recovery of energy; in this we were assisted by the experiments made, for instance on the Burgdorf-Thun line. It was found, even on main lines with steeper gradients than are found under our average conditions, that the energy recovered is at most 3 to 4 per cent of the total energy. Taking the average conditions of our railways into consideration, this figure becomes appreciably reduced, and hence there is no need for considering further the subject of the superiority of three-phase current from this point of view.

It should however be remarked that such recovery is also possible in the case of single-phase current, perhaps in as simple a way as in that of three-phase current.

An important point is the strength and safety of the contact lines. The recent types of overhead lines, with multiple suspension, etc., are very much improved; as they make it possible to use high voltages, their economic advantages as compared with the third rail which can only be used with low voltages, are so much greater that the latter will be given up generally in spite of its indisputable superiority from the point of view of strength. Moreover, a one-pole overhead line certainly gives much less trouble than a two-pole line, and this is an appreciable advantage in favour of single-phase as compared with three-phase current.

Much information is available as to the disturbances in telegraph and telephone lines produced by the power lines of great railways. I must mention in particular the results obtained on the single-phase Seebach-Wettingen line. They showed that the disturbances were due less to high voltages than to higher harmonics of high frequencies, resulting from the use of open and straight slots in the commutator motors, but that it was easy to remedy this by suitably modifying the construction of the motors. Moreover, the measures to be adopted for the telegraph and telephone lines are the same whatever the system of current. From this point of view, there is hardly any

difference between the different systems.

I will not dwell on the reasons which have led us also to adopt a frequency of about 15 periods.

Let us now pass to the *comparative cost*. It cannot be based on the results obtained on the different lines of the existing electric railways, because the cost of different transport enterprises is too much influenced in each individual case by special conditions. We have based it on carefully-worked-out complete projects, which include the capital outlay and working expenses of definite systems, so as to enable us to decide for ourselves — apart from the question of system — whether electric operation, with use of water-power, is cheaper than steam operation. Our results naturally in the first place only apply to the railway systems considered; taking into consideration however their nature, they will apply to most of our more important lines. As an example, we will take the projects for the St. Gothard line, which are based on a traffic much busier than the existing traffic, with speeds much higher than existing speeds, the train loads being the same, and having the same onerous double express trains in the middle of the day, etc. (for the data see our report). The two projects, called A and B respectively, assume traffics 25 and 69 per cent heavier respectively than the steam-operated traffic in 1906, the traffics, *excluding* the weight of the locomotives, being 36 and 84 per cent heavier than in 1906. The unit prices used for determining the capital outlay and the working expenses were taken from the investigations of manufacturers and of the railway administrations. The results are given in detailed tables annexed to my report.

The capital outlay for the distributing system proper (substations and overhead lines) amounts, in the case of direct current, to about 25 millions of francs (£1 million), in that of three-phase current, without equalizers, to about 7 millions (£280,000), and with equalizers to about 15 to 16 millions (£600,000 to £640,000); in the case of single-phase current, without equalizers, to about 2 $^1/_2$ millions (£100,000), and with equalizers to about 10 and 11 millions (£400,000 and £440,000).

The total cost of the energy proper, delivered at the contact wire, calculated in the first place for purposes of comparison by adopting a corresponding price at the power stations, on the other hand, shows in the case of traffic A:

Direct current	about 5·3 to 6·2	million francs	(£212,000 to £248,000)	per year.
Three-phase current . . .	— 3·8 to 5·4	—	— (£152,000 to £216,000)	—
Single-phase current. . .	— 3·0 to 4·6	—	— (£120,000 to £184,000)	—

The lower price corresponds to a power station supplying all the power, without equalizers in the systems; the higher price on the contrary corresponds to a system with equalizers and a proportionately smaller power plant. The latter system is accordingly less favourable, as has already been stated above. Seeing, on the other hand, that the other costs, more particularly the cost of traction proper, only vary very little with the three different systems, the economic superiority of the single-phase current is already made apparent by the above figures.

The outlay on rolling stock proper (locomotives and automotor cars) amounts in the case of single-phase current to about 13·5 to 16 millions (£540,000 to £640,000) [15 to 25 periods] and in that of three-phase current to about 12·5 to 14 millions (£500,000 to £560,000); in that of direct current it is much higher and we will not consider this now.

The cost of the power stations and the cost of operating them, as determined in the general projects, have given slightly lower figures for the cost of energy than those which we have given. According to the latest calculations, the power stations can have somewhat smaller dimensions than those assumed in the calculations given in table E of our report. According to this table, the total capital outlay for electric traction on the St. Gothard lines (power stations, distributing system, contact wire, motors, rolling stock, etc.) amounts with :

Traffic A, single-phase current, to.	66	million francs	(£2,640,000).
— three-phase — to about	72	—	— (£2,880,000).
Traffic B, single-phase current, to.	79	—	— (£3,160,000).
— three-phase — to about	83	—	— (£3,400,000).

and the total annual expenditure to about :

With steam traction, traffic of 1907.	8·9	million francs	(£356,000).
— — — — of 1908.	9·3	—	— (£372,000).
— electric traction, traffic A, single-phase current . . .	9·2	—	— (£368,000).
— — — — three-phase	9·8	—	— (£392,000).
— — — traffic B, single-phase	10·7	—	— (£428,000).
— — — — three-phase	11·4	—	— (£456,000).

The single-phase system is accordingly economically superior to the three-phase system; the inferiority of the direct-current system has been sufficiently demonstrated by the figures previously given.

The two electric systems are accordingly cheaper than the existing steam system. The working expenses for traffic A with single-phase working are for instance in between those of 1907 and 1908 with steam working, although traffic A includes 18 per cent more traffic, locomotives not included.

The net cost per ton-kilometre is, with steam, 0·81 to 0·88 centime (0·127*d.* to 0·138*d.* per English ton-mile); with single-phase current, 0·70 to 0·61 centime (0·110*d.* to 0·096*d.*); and with three-phase current, 0·76 to 0·65 centime (0·119*d.* to 0·102*d.*).

Other figures will naturally be obtained for other railway systems and other water-powers.

In our case, these figures will be applicable in practice.

We think we may say, as regards Switzerland, that the electric operation of main railroads is technically possible and will even be satisfactory.

It will hence be possible to introduce the single-phase system with high-voltage overhead wire, a system which has given satisfactory results. It will be possible,

by using water-power, to reduce the cost of traction as compared with steam traction.

One important point, which must not be forgotten, is the following : the electrification of the standard-gauge lines involves the outlay of a vast amount of capital, and it is hence necessary to examine the question with great care, although the problem may be considered as solved from the technical point of view.

I will refrain from enunciating any personal conclusions; I have already occupied too much of your time. I will merely state that the conclusions I feel inclined to draw agree astonishingly with those of the two reporters who have already spoken before me and that — I note it with pleasure — without any previous consultation. Each report was drawn up independently. I therefore hope that in presence of this unanimity, the Congress will give an impulse towards the adoption of as uniform a system of electric traction as possible. I hope that the work of the Congress will result in a certain solution, at least as far as Europe is concerned. I do not think the difficulties are great enough to prevent our coming to an agreement about the main points, namely the system, the frequency, perhaps also the voltage in the contact wire. (*Applause.*)

Mr. Krasny, Austrian State Railway. (In German.) — I will only ask for your attention a few minutes. The statements of the reporters give an agreeable impression of uniformity in the theory of technical problems which may be considered as solved or as about to be solved. The administration and legal questions only become all the more important. I will not lay stress on the economic difficulties. The concise statement with which Mr. Wyssling concludes his report, that " the electrification of standard gauge railways will involve the outlay of a vast amount of capital ", seems to sum up the problem. It is not only necessary that electric traction should be cheaper than steam traction from the point of view of working expenses proper; but the difference must be large enough that the vast capital required, on the one hand, for the electrification, and, on the other, becoming unproductive in the case of material used for steam traction only, may be remunerated by the saving effected. It is this consideration which has somewhat shaken my optimism in electricity. I do not think it likely that this problem will be solved as soon as had hitherto been hoped. It is however not so much this question to which I would draw your attention, as another, which seems to me to be of capital of importance.

The railway service has given rise to the birth of international conventions of an economic order. It was the railways who first made international agreements relating to technical and administrative questions, conventions which chiefly have the object of leading to uniformity in certain services and of favouring the free circulation of rolling stock. Now it is to be feared, unless precautions are taken in due time, that the adoption of electric traction may make a break in this uniformity in the railway service, arrived at with difficulty. There are many chances that the adoption of electric traction on the main lines of traffic may have as result that the free circulation of rolling stock and of goods may be stopped at the fron-

tiers. Accordingly one cannot too much emphasize the exceptional importance of urging the railways and governments concerned to agree in good time on the question of principle affecting electric traction. However the adoption of electric traction may start, the whole problem arises, and the installations of each individual line will influence the electrification of the whole system. Hence the great difficulty and hence the extreme prudence necessary when starting to select the system of current, the voltage, the frequency, etc. One must consider with each individual line not only what position it will take in its own national system of railways, but also its relation to the international system of railways.

I will content myself with mentioning one sole point of exceptional importance : that is the military and strategic side of the question. Electric traction cannot become general if the free circulation of traffic for strategic purposes is not also practicable. I hence feel inclined to think that it would be extremely important for the International Railway Congress, intended above all to establish uniformity between civilized nations as regards railway questions, to investigate the question whether it would not be useful, if not to conclude, at all events to prepare an international convention relating to this subject. I will remind you that, as regards railways, such international agreements already exist, for instance the convention of 15 May 1883 which fixes the gauge of the line and the particulars of the rolling stock, so that the latter may be utilized everywhere. Similarly there are international conventions relating to the carriage of slow-freight goods, with a central office at Berne. On 3 November 1906 an international convention was signed at Berlin, relating to wire-less telegraphy, which declares that all wire-less telegraphy systems are equivalent in law. The problem which now arises appears to me to be quite analogous. It is equally a question of fixing certain technical details relating to system of current, to voltage, to frequency. Conventions made between *railway administrations* become insufficient from this point of view; it is necessary that *governments* should make agreements so as to obtain uniformity at all events in the countries interested in European railway traffic. I think that it is necessary for this purpose to provide for the calling together of an international conference. Although the International Railway Congress, at which governments are only represented by their delegates, is not in a position to draw up conventions of this kind, I propose to submit to the Permanent Commission the question whether, and under what conditions, one could prepare an international convention relating to the technical details of electric traction : system of current, frequency and voltage. Finally, the Permanent Commission could enter into relations with the governments with a view to the summoning of an international conference.

It may perhaps be objected that these precautions are premature. While inversely conventions of this kind follow the drawing up of regulations in the different States, it is in this case of the highest technical and economic importance that international regulations should precede those of the different States. Without prejudice to the conclusions arrived at by the reporters, I will accordingly allow

myself to propose the insertion, in the conclusions, of a sentence stating that it would be useful to start negociations with a view to international uniformity in questions of principle affecting electric tractions.

Mr. Wyssling, *reporter*. (In German.) It seems to me that mistakes can be made with reference to the cost of traction which I have mentioned. I will remark that in the total expenditure mentioned, as well as in the cost per ton-kilometre, all payments for interest are included. This is explained in detail in my report. Not only the interest is included in the calculations, but also the cost of renewals and of the amortization of all these new costly installations, so that the reduction in the cost of electric traction is in spite of the vast capital expenditure involved.

The President. (In German.) — If I understand you correctly, the capital which may be considered as lost in consequence of the adoption of electric traction, that is to say the capital representing the locomotives, is included ?

Mr. Wyssling. (In German.) — Yes.

Mr. Gleichmann, *reporter*. (In German.) I should like to remark that it is well understood that in comparing the cost of steam traction with that of electric traction, allowance has been made, in the case of electric traction, not only for the maintenance of the transmissions, etc., but also, in all cases, for the cost of renewals, for interest and for amortization. It is subject to these reservations only that one must understand the economy of electric traction as compared with steam traction. I have mentioned that in Mr. Jacqmin's extract published in the *Bulletin*, all these factors are included. It is very difficult to form any estimate of the life of an electric locomotive ; hence one is reduced to approximations. Now the figures have been taken as high as possible, so that it may be foreseen with safety that the costs determined by the calculations are high enough.

I will also say a word about Mr. Krasny's remarks. As Mr. Wyssling has already emphasized, I think, that the adoption of electric traction will not come about quickly.

Mr. Nicoli, Italian State Railway. (In French.) — Gentlemen, I wish to address the meeting in order to make a communication, which is I believe of considerable interest.

In Italy, at the beginning of last month, there was completed the electrification of a line which is very noteworthy on account of the magnitude of its traffic as well as from the point of view of the working difficulties.

In order to cross the chain of the Appenines immediately to the north of Genoa, we have at present, between Genoa and Ronco, two double-track railways with steep gradients : the old Giovi line which between Pontedecimo and Busalla has a steepest gradient of 35 per mil in the open and of 29 per mil in the tunnel which is nearly 3·5 kilometres (2·2 miles) long ; and the new line known as the "*Succursale dei Giovi*" which has gradients of 16 per mil in the open and of 12 per mil in the great tunnel which is 8 kilometres (5 miles) long. But the traffic of the port of Genoa is continually increasing and it is possible that in a few years the lines

north of Genoa will no longer suffice and that it will then become necessary to build another line. In the meantime, in order to work the traffic with the existing lines, the old Giovi line has been electrified. It is evident that as this line was operated by means of very good steam locomotives with five coupled axles, the simple substitution of electric locomotives for steam locomotives would have had but slight advantages if the speed of all trains had not been increased at the same time. However the electrification of the Giovi line was carried out in order to increase the traffic capacity, by increasing the speed, even of goods trains, to 45 kilometres (28 miles) per hour. In this way it becomes possible to convey 1,500 wagons per day over this line. It is self-evident that as now the trains will have two locomotives, one at the head of the train and one at the tail, so as not to exceed the strength limits of the buffing and draw gear.

One has in this way to be led to build electric locomotives with two motors and five coupled axles, having a total weight of 60 tons, all adhesive, and with a normal output of 2,000 horse-power. If experience shows this to be desirable, it will be possible, by means of ballast, to increase the weight of these locomotives to 75 tons. Numerous trials, which have all given good results, have already been made; trains weighing 320 tons (locomotives not included) have been hauled by two locomotives, at a speed of 45 kilometres (28 miles) per hour, and trains weighing 380 tons at one of 22·5 kilometres (14 miles) per hour.

It was recognized that in order to haul 380-ton trains at a speed of 45 kilometres per hour it was necessary, in order to ensure adhesion, to weight the locomotives. In consequence of these very favourable results, it has been decided to start a regular service with electric locomotives very soon (1).

In order to allow those interested in the question to obtain full particulars of this electrification, I will hand the President a short description of this work, together with some photographs (see annex below), and I will add that up to the present the electrification is limited to the section between Busalla station and Campasso shunting yard, but that it will soon be extended. The system adopted in this case has been three phase current and 3,000 volts in the contact wire. It was considered that this system gives good results in the Valteline and that the possibility of using higher voltages in the contact line in rather long tunnels has not yet been proved. The power station has a steam plant and is located at Genoa in the immediate proximity of the port, where the coal will be conveyed to the boiler house by means of of a coal-conveyor. The station includes two turbo-alternator sets each capable of a continuous output of 6,250 kilowatts,

(1) I must mention, in revising the text of my communication to the Congress, that after steam traction had first been reduced and then abolished on the Pontedecimo-Busalla line, the condition of the track became much improved from the point of view of adhesion; for several months now, this line has been operated normally, even on the steep gradients of 29 and 35 per mil, with trains weighing 190 tons hauled by a single locomotive at speeds of 45 kilometres (28 miles) per hour, and with trains weighing 380 tons also at speeds of 45 kilometres per hour, hauled by two locomotives, without these locomotives, which have a total adhesive weight of 60 tons, being weighted with extra ballast.

and of an output of 10,000 kilowatts during five minutes.

I think it useful to add that my administration has already undertaken the electrification of the Mont Cenis line between Bardonnèche and Modane; this work will be finished spring 1911, at which time the Turin international exhibition opens, if no unforeseen difficulties arise.

The Savona-Ceva line will also soon be electrified; this has a single track with gradients of 25 per mil and there is a considerable amount of traffic. Moreover, the electrification of the Valteline line will be extended to Milan. Finally it has already been decided to transform the electric installations of the Milan-Gallarate-Varese line, keeping to the direct-current system; the importance of this line is continually increasing since the Simplon tunnel was opened. The object is to extend the use of electric traction to the goods trains and to make it possible to increase the weight of the passenger trains, of which there are already too many.

It should be mentioned that our new applications of three-phase electric traction are only consequences of the good results of the system used in the Valteline, and that we intend to reject neither the direct-current, nor the single-phase system, of which we will probably shortly make an experimental application on the Turin-Pinerolo line.

Mr. Salomon, French Eastern Railway. (In French.) — Mr. Krasny has mentioned the advisability of coming to an immediate agreement with a view to the unification of the system of electrification for lines carrying international traffic. Allow me two remarks in connection with this question.

In the first place, the discussion which has just begun shows that we are far from agreed at present as to the best system of electrification.

The Italian delegates recommend three-phase current, while several of our colleagues are in favour of single-phase; accordingly the time has not yet arrived when we can say which is the best international system.

In the second place, and this is perhaps the most important observation because it is a question of operation, it is certain that the international traffic will be operated, tomorrow like today, whatever the system of electric traction adopted in each of the States. Every one will have his own stock. There will perhaps be some little troubles at frontier stations, but it will be easy to overcome them by putting up somewhat different contact lines.

The President. (In French.) — Gentlemen, I do not wholly agree with Mr. Salomon and I ask your permission to bring before you my own personel opinion.

Our association only meets once every five years. If we do nothing now, five years will be lost, between now and the next session. On the other hand, nothing will be lost if the Permanent Commission, at the request of the whole Congress, addresses the different governments and asks them to constitute an international commission. (*Interruption.*) Although there may be commissions which lead to no result, there are others which do. (*Laughter.*)

I think therefore that an international

commission such as Mr. Krasny suggested could do very useful work. It could at least prevent the different systems from becoming too diversified.

I perfectly agree with Mr. Salomon that we do not yet absolutely know which is the best system to adopt. We have just heard that Italy is in favour of the polyphase system, while most of the reporters recommend the single-phase system. I think however that a certain unification in electric operation would be desirable and that a commission appointed with a view to arriving at such a unification might have good results; just as the German *Verein* every day settles questions of working, and as other technical points have been settled by an international commission.

Mr. Flury, *vice-president.* (In German.) — Allow me to make a remark about this subject. I think that the points mentioned with a view to an eventual international agreement can very well come within the scope of international technical uniformity. An organization for cases of this kind already exists. You know that the Swiss Federal Council has been requested by all the States of Europe to summon from time to time a conference for dealing with international technical uniformity. It will suffice if any one of the administrations proposes to the government of its country to ask the Federal Council to place this question on the agenda of the next international session. I think we will wholly attain our object in this way and I think that any new organization is unnecessary.

Mr. Steinbiss, *vice-president.* (In German.) — I will venture to remark, in this connection, that in my opinion it is not advisable for the Permanent Commission to address the governments. That is not its function. I also think that the creation of a special commission, which we should have to regard as a permanent technical commission, will be recognized to be unnecessary. It seems to me advisable to adopt the plan suggested by Mr. Flury and to have recourse to the Technical Uniformity Commission.

Mr. Flury. (In French.) — The question could be submitted to the Technical Uniformity Commission at its next meeting.

Mr. Ernest Gerard, *vice-president.* (In French.) — We can say, at the end of our conclusions relating to subject VIII, that the Congress leaves the care of obtaining the necessary uniformity to the bodies competent to obtain the agreement of the different governments concerned.

Mr. Hruschka, *reporter.* (In German.) — The question of unification is facilitated to some extent by the very nature of the single-phase system. This latter has the advantage of working, up to a certain point, with direct and with three-phase current. Provided that the vehicles are fitted with the appliances necessary, single-phase vehicles can run on lines supplied with three-phase or with direct current. This peculiarity, which is a distinguishing feature of the single-phase system, is in favour of this system because one is sure *a priori* that later on a small modification of the vehicles will suffice to enable them to run in neighbouring countries.

I will also remark that in all properly-drawn-up accounts of working expenses,

amortization and interest are included, consequently also that part of the steam traction plant which will be rendered useless.

My third remark is that I consider that the international conference would be extremely useful, but I think that I should proceed slowly. However technical uniformity should be prepared for. I am of opinion that the railway administrations should for the moment come to an agreement between themselves. In this less formal shape, each railway management will be more likely to join than if the slower method of an international conference is adopted. In any case, I must remark that the different systems of current are of different value in different countries. A country cannot be ordered to select a system which is not the most advantageous for that country.

Mr. Merczyng, Russian State Railway. (In French.) — Gentlemen, allow me to give you some particulars about the state of the question of electrification in Russia.

Mr. Wyssling's report says nothing about our country, and in fact, as regards electric railways in operation, we as yet possess nothing. We only have two small lines of a local character, one 25 and the other about 10 kilometres (one 15·5 and the other about 6·2 miles) long. We are however on the point of making great progress in this direction; thanks to the stimulus given by the State Duma and by the ministry of ways of communication, the electrification of several of our railways will be begun.

The question of electrification is always an important one and that in the first place from the point of view of economy, that is to say, from the point of view of the net cost of the current supplied by steam plants or water-power plants. Fortunately we possess much water-powers in Russia; I do not talk of large waterfalls as in Switzerland, but of our large rivers which have rapids down which vast quantities of water flow, with a medium or small fall. These rapids can supply tens of thousands of horse-power and it is a question of acquiring them in order to be able to utilize the energy supplied for the electrification of certain railway systems in our country.

The State Duma has just voted a credit of 80,000 francs (£3,200) with a view to investigating the utilization of water-falls near St. Petersburg, at a distance of about 30 kilometres (18·6 miles) from that town. These falls can supply as a minimum 33,000 horse-power during winter, and much more during the summer. The current supplied by these falls will go to St. Petersburg and there probably will be utilized for the electric operation of some of the railways terminating there; perhaps also for the Metropolitan and for haulage on the canals in the city.

We also have great rapids on the Dnieper. Projects for the utilization of these rapids, which can supply tens of thousands of horse power, are already well under way. The idea above all is to supply power to works, but this large water-power can also in addition be used for other purposes, for instance for the electrification of certain small railway lines. We have the hope, if not of realizing the utilization in the direct future, at all events of soon arriving at a decision on the subject.

The Russian railway administration is

also thinking of electrifying a Transcaucasus line. Steam traction does not make it possible to have as many trains on that line as are required. As it is near the rapids of the Rione river, it is probable that it will be possible, with the help of these rapids, to effect this transformation.

I may also mention three rapids or series of rapids which will probably be utilized in the immediate future; namely those of Kivatch in the north of Russia, those of the Niemen in the west, and the Terek water-falls in the Caucasus.

According to a scheme which has been drawn up, the Niemen rapids, which are near the German frontier, will give 30,000 horse-power which can be utilized for chemical works and also for the electrification of a steam-traction line which it is proposed to extend in that neighbourhood.

The Kivatch rapids in the north will probably also supply the energy necessary for the electric operation of a line which it is proposed to build in that district.

In Russia there is at present a special commission, of which I have the honour to be president, which is investigating the utilization of hydraulic powers for the production of electric energy, and I hope that at the next session of the Congress the Russian delegates will be able to give you information, not only about schemes as I am doing now, but also about lines in operation.

Mr. Jullian, French Midi Railway. (In French.) — Gentlemen, I request that I may be able to say a few words about what the Midi is doing in the way of electrification.

The President. (In French.) — I regret it, but several delegates have put down their names before you and the time for adjourning the meeting has come.

Mr. Jullian. (In French.) — Mr. President, I cannot be here this afternoon and hence I should be obliged if you would allow me to speak now.

The President. (In French.) — I will call upon you to speak.

Mr. Jullian. (In French.) — Gentlemen, the French government had asked the Midi to take over the concession for a line which had up-gradients of 40 per mil and curves with a radius of 150 metres (7 1/2 chains) and which consequently is not within the scope of its regular working limits.

The President. (In French.) — This is no doubt a line in the Pyrenees?

Mr. Jullian. (In French.) — Quite so. In order to induce us to take over this concession, the government proposed to us that this line should be an electric line, and offered that it should make all the necessary dams and weirs, etc., up to the power station. Moreover, it would give us the cables and the contact line.

Taking these offers into consideration, we investigated the question, and after investigation we thought that it was of some advantage to us to accept these conditions.

We then decided to electrify at the same time 400 kilometres (248 miles) of our system. The pecuniary advantages which this transformation will give us will not be great at the start, but it will give us advantages of another kind, secondary advantages, for instance from the point of

view of obtaining employees, a question of great importance at present to the whole world, and from the point of view of the speed on our Capvern gradient, where our expresses do not at present succeed in attaining a speed of 30 kilometres (18·6 miles) per our uphill. The gradient there is 33 per mil.

We have naturally investigated which form of current would be most favourable. It is a question of a system of 400 to 500 kilometres (248 to 310 miles), to which I am drawing your attention, and we have selected single-phase current. Moreover, for the reasons mentioned by Dr. Gleichmann, we have adopted a frequency of 16 $^2/_3$ periods per second and a voltage of 12,000 volts.

Before undertaking the general electric equipment of our lines, we are going to make trials on this basis. Our power stations are already being built, but we have not yet decided about the type of locomotives. We have applied to six firms, to the *Allgemeine Electrizitäts-Gesellschaft*, to Creusot, to the Northern and Eastern Electric Works, to the Westinghouse Company, to Thomson-Houston and to the Brown-Boveri Works, all of whom have undertaken to send us a pattern locomotive or automotor car for trial. Our trials will begin in the second half of October; for this purpose we will equip a line 25 or 30 kilometres (15·5 or 18·6 miles) long with single-phase current, and we hope that by the beginning of next year we will have been able to decide upon one type.

We shall also have at these trials a 400-horse-power automotor car, supplied by the Havre Westinghouse Company.

Allow me to add a word on yet another point. The unification of the types of locomotives was talked about some little time ago. I must see that I do not see the advantage of this unification.

The President. (In French.) — It is not a question of the unification of the types of locomotives, but of the unification of the installations, the question of the selection of locomotives being absolutely excluded.

Mr. Jullian. (In French.) — Nor do I see the advantage of the unification of the systems.

Gentlemen, I now conclude, but before doing so I wish to thank the President for kindly having allowed me to speak this morning.

Meeting held 11 July 1910 (afternoon).

The President. (In French.) — We will resume the discussion of subject VIII.

Mr. Graftio, Russian State Railway. (In French.) — Gentlemen, I wish to say some words in connection with the summaries which we heard this morning.

If we can today join in interesting discussions, if we know today instances of epoch-making electrifications, it is because American firms like the General Electric Company and the Westinghouse Company, German firms like the *Allgemeine Electrizitäts-Gesellschaft* and the

Siemens Works, Hungarian firms like Ganz, and Swiss firms like the Brown-Boveri Company and the Oerlikon Works, have worked at the solution of the problem and have obtained results which astonish the world and by which we now benefit.

It seems to me that it would be premature and perhaps even very dangerous to recommend one given system of traction and to say for instance that the single-phase system must be or must become in a more or less near future the universal system to be adopted by preference.

We are, in fact, in the presence of too many uncertain data, and our deductions may differ widely according to the information we have available and the calculations we make on the basis of these data.

Several advantages have been mentioned in the case of single-phase current which in the opinion of some entitle it to preference : the simplicity of the overhead lines, a certain flexibility in train speeds, the possibility of working with a satisfactory load curve at the power station and of obtaining speeds varying with the gradients, and finally less capital outlay and lower cost of maintenance.

I think, gentlemen, that it would be possible to arrive at conclusions which would not at all agree with those which have been brought before us. If one considers the contact lines alone, the single-phase system evidently has this superiority over the three-phase system, which everybody must appreciate, that it is only necessary to have a single conductor for the contact line and not to have two wires with a difference of potential; and if we compare this system with the others, it seems at first sight that the cost of construction of a single-phase overhead line must be much lower than, for instance, that of a three-phase line. That is practically the case with experimental lines or railways lines of secondary importance, where a simple and plain distribution may be considered sufficient and satisfying all needs.

But we can consider cases of quite a different character, cases which will soon have to be investigated, for instance the case of applying electric traction on main lines with busy traffic, on trunk lines of great importance. In those cases we must not only consider economy pure and simple; we must also ensure, if electric traction is to be used, that the distribution is reliable, and in our different countries we must take into consideration the possible need of conveying troops with all desired safety and certainty. That, in many countries, is a question which hinders the introduction of electric traction; and if we examine it more closely, we will perhaps arrive at figures somewhat different from those which the reporters have taken as basis in estimating the prime cost of the contact lines and cables with the different systems of electric traction.

When it is a question of lines of considerable importance, care must be taken to provide against any interruption in the service. It will be necessary, as has already been pointed out in several technical journals, to solve the question by having a double set of cables for the high-voltage supply, to divide the line into sections by pillar switches, to provide for changes in the connections of these lines. It is necessary that it should be possible to cut out from the circuit the lines of each section between two stations or two

passing places or the lines of each station or of each passing place without cutting out the adjoining section. It must, finally, be necessary, in case of a break-down at any one sub-station, to be able to have recourse to the two nearest sub-stations without interrupting the service. Under these conditions, and with the voltages of 3,000 to 5,000 volts which are now adopted, we can in the case of three-phase current have sub-stations 5, 6, 7 or 8 kilometres (3·1, 3·7, 4·3 or 5 miles) apart in undulating country; this distance can be increased to 9 and 10 kilometres (5·5 and 6·2 miles) in less undulating country. Now in this particular case it would be very easy to cut out any section of the line between two stations or passing places; or in case of a break-down at a sub-station it would be very easy to feed the corresponding section from to the other two nearest sub-stations. At the same time the double set of cables would give considerable security against any extensive break-down in the service.

In the case of the single-phase system, such as it actually exists and with a voltage of 10,000 to 15,000 volts in the contact line, we are able, in the case of railways of a secondary importance where a break-down in the service would not lead to much trouble, to have sub-stations 30 to 40 kilometres (18·6 to 25 miles) apart without using supplementary feeders at the same voltage. Such a line would not cost much.

But on lines with much traffic, on lines of great importance where electric traction must satisfy conditions in any case, it is necessary to have a rather more complicated distributing and feeding system. We must either have the sub-stations closer together, or a system of feeders which makes it possible to cut out any of the sections between two stations or two passing places, and properly to feed any section of the lines from the neighbouring sub-stations if there has been a break-down at the intermediate sub-station. We must also provide for duplicating and dividing the high-voltage line, as already stated above.

Under these conditions the ratio between the cost of constructing lines of the two different systems becomes very different and we find figures for the single-phase system and for the three-phase system which approach each other closely; perhaps there is a small difference in favour of the single-phase system, but it is quite an insignificant one.

As regards the machinery required to equip the power stations, we obtain a rather lower figure with three-phase current than with single-phase; I will not say how much, for it is a difficulty to fix an accurate figure at present, but something like 5 to 10 per cent. On the other hand, we always obtain a higher figure with single-phase than with three-phase or direct, when we consider the rolling stock, the electric locomotives. (Single-phase locomotives cost and will cost one and a half times as much as three-phase locomotives of the same power, and at the same time weigh about one and a half time as much.)

In Russia much attention is devoted to the question of electric traction and the management of the State Railway has recently occupied itself with schemes for the electrification of several lines. It has considered, among others, the electrification of two Transcaucasus railways which

have rather steep gradients, of up to 29 per mil; they are both single-track, heavy trains run on them and water-falls in their immediate neighbourhood are available. Calculations have been made for these two lines in order to determine the comparative cost of the single-phase and of the three-phase systems, and it was found that three-phase gave a figure lower than single-phase.

Last year a special commission was appointed by the management of the Russian State Railway, in order to study the electrification of the St. Petersburg suburban lines, which have a total length of about 120 kilometres (74·5 miles), one connecting line crossing the town itself; it was assumed that the energy necessary should be obtained at the Volhoff rapids, 120 kilometres to the east of St. Petersburg, and conveyed as three-phase current at from 80,000 to 110,000 volts. The comparative investigations which have been made seem to show that in this particular case it would be preferable to use high-voltage direct current outside the town, and to use the same direct current but at a low voltage, with a third rail, on the elevated section crossing the city.

In the towns, æsthetic considerations have also to be allowed for; moreover, overhead lines on poles are not convenient and it is better to use the third rail.

As regards to distributions of the energy and the transmission of the power obtained from the Volhoff rapids (representing about 30,000 horse-power to be utilized not only for traction but also for other purposes), the three-phase system shows itself to be that best suited for utilizing the surplus of energy available for other purposes. In this special case, as regards the traction proper, direct current proves unfortunately to be indicated.

Finally, lately a private company has been considering the question of a proposed line in the Crimea, a line with a large passenger and goods traffic and connected with the State Railway system; this line will have gradients of 40 per mil and electric traction will be used, the power being generated by a steam plant. In the case of this new line two schemes have been worked out, one with single-phase current, the other with three-phase, and it was determined that of the two systems the three-phase would give the better results, not only as regards capital outlay and working expenses, but also as regards reliability of working and certain other technical advantages.

When one considers the special case of mountain lines from the point of view of the running of trains, one arrives at very original results. On such lines, the safety of the traffic must be ensured as much as possible by the proper braking of the trains. At present, in all countries, goods trains include a certain number of braked cars and it is always disagreeable to have to vary the number of brakes of a made-up train.

Thus one arrives at quite different results in the case of single-phase current which owing to the variable speeds (which are the essential feature of this system), involves the necessity of increasing the number of brakes and of running under conditions which are similar to those of steam trains and are by no means favourable, and in that of three-phase current which makes it possible to obtain automatically great speeds on up-gradients and moderate speeds on down-gradients, that

is to say, speeds which do not involve the necessity of increasing the number of braked cars in the train, seeing that the moderate speed on down-gradients is automatically maintained by means of the automatic recovery of energy as you all know.

As regards the point of view of the running of the trains and of the traction, perhaps our ideas are involuntarily falsified by our experience and knowledge of steam traction and of urban electric tramways. Our steam locomotives run at very varying speeds, at low speeds on up-gradients, at high speeds on the flat and on down-gradients. In the case of tramways, we are also accustomed to the speeds of the series motor. If we clear ourselves a little from our preconceived notions, we arrive, I think, at the conclusion that from the point of view of traffic proper, from the point of view of operating railways, a system which would allow us to obtain one or more uniform speeds affected neither by up nor by down gradients, nor by the personal equation of the drivers, would give the best results. From this point of view, surprising examples are to be found in the country in which we are at present, as well as in the neighbouring country Italy. And what seems surprising is that the load curve at the power station is by no means less favourable with three-phase than with single-phase current.

We can in this way arrive at having time-tables which will be followed more exactly than with any other system. We will hence attain greater safety, for numerous accidents occur on down-gradients when brakes are applied when the speed is already too great ; this risk will then be eliminated.

To sum up, taking into consideration all that we know, I think that it would for the moment be dangerous to recommend any one system. As regards for instance our country, which is of large extent, one can not expect the general electrification of all the railway systems. We have lines in the plains, mountain lines, main lines, secondary lines ; and the same state of affairs exists in most other countries. At present even in the case of steam traction, the locomotives used on the plains are not used on the mountain lines ; nor are the mountain locomotives used on the lines in the plains. Trains pass from one district to another, but at the point where the character of the line becomes modified, one simply changes the locomotive.

We could do the same in the case of elecric traction. We could have in the different districts of the country, and according to circumstances, one or the other of the three different systems, direct, single-phase or three-phase ; there would be no difficulty in changing the locomotive at the junction point. In the country where we are, we see that one even goes further : there are points where it is absolutely necessary even to change trains, for instance in the Oberland, to go to the Jungfrau. Nobody complains about this ; everybody understands that it was necessary to adopt whatever system was most economic and most favourable under the circumstances.

I repeat, it is accordingly premature to recommend at this moment any one system. If we have met here in order to discuss electric traction, it is to private initiative, to its freedom of action that we owe this. Let us therefore let it con-

tinue, without restraining it within doubtful limits, and it will certainly act in such a way that in five years, when we meet again, we shall be able to speak much more generally. (*Hear, hear !*)

Mr. Paul-Dubois, *principal secretary.* (In French.) — Genlemen, the remarks I wish to make are similar to those which Mr. Graftio has made.

All or nearly all the reporters are in favour of the system which implies the exclusion of single-phase current. Now although we today know fairly well the character and the limitation of the use of the three-phase direct system and of the purely three-phase system, thanks to the results obtained on the lines on which these systems have been in use for several years, that is not the case with the single-phase system.

Ever since the latter first appeared, its promotors represented it as a revolution in electric traction owing to the economies it would effect as compared with the other systems. I should have liked to see some definite figures in support of this prophecy, some practical results showing the cost of construction and of operation of main railroads operated by means of single-phase current. Instead of that, we have hardly had anything except figures given in projects; these figures are certainly very interesting, but they are necessarily rather of a doubtful character.

Moreover, some of the information which we have received gives rise to reflections. For instance, the comparison of the suburban lines Berlin-Grosslichterfelde and Hamburg-Altona shows that if the net cost per kilowatt-hour is lower with the latter, the working expenses per ton-kilometre are on the contrary about 50 per cent higher; now the Hamburg line uses single-phase current and the Berlin line direct current. On the other hand, according to the estimates for the proposed line Murnau-Oberammergau, there is, between direct and three-phase, only a difference of 7·3 per cent as regards capital outlay and of 7·8 per cent as regards working expenses; these differences are of the same order of magnitude as the errors in such estimates.

As regards the importance of the capital outlay in the case of single-phase current, Mr. Wyssling's very interesting report gives figures for the St. Gothard line which are worth attention: the capital outlay will vary between 250,000 and 350,000 francs per kilometre (between £16,100 and £19,300 per mile) according to traffic. It is true that according to the estimates made, the working expenses will be lower than with steam traction; but in this estimate interest, amortization and renewals are only taken at about 3 per cent, evidently a low amount.

Some of the reports seem to give the impression that various countries have the intention of adopting electric traction in a general manner on thousands of kilometres of railway line. That is a false impression and that idea must not be allowed to take root. I do not dispute that there are certain lines with special conditions, where the substitution of electric traction for steam traction can be advantageously realized from the point of view of economy, but it is absolutely impossible to generalize.

In order to give an example which I know personally, the Orleans Railway,

which was one of the first to adopt electric traction, which has utilized it on its suburban Paris lines for about ten years, and which follows the subject with great attention, has quite recently investigated whether there would be any advantage in introducing electric traction on other sections of its system, and has found that with all its 7,000 kilometres (4,350 miles) of line, there is not one section in which there would be an advantage in this introduction. I may add that it has arrived at this conclusion quite apart from other considerations which are nevertheless of importance, such as cases of war or of trouble. It is certain that an electric-traction system is eminently more vulnerable than a steam traction system. The recent floods in Paris proved this; the resumption of the service was much slower in the case of electric traction than in that of steam traction as all the power stations in the district effected, except one, had been stopped by the floods.

Another observation to be made in connection with the introduction of electric traction on railways concerns the collecting of the current. This collection is the weak point of the single-phase system. The different devices used are still new; they are still in a state of evolution and it seems premature to give any definite opinion as to their practical value for the purposes of the main railroads, which are all that I am at present considering.

I conclude that at the present time it is very difficult to lay down that one kind of current should be used, to the exclusion of other kinds; the choice is essentially a question of kind. Moreover, we may also have to reckon with surprises which such a rapidly-progressing science as that of electricity may spring upon us.

Mr. Mazen, *principal secretary*. (In French.) — Gentlemen, I absolutely share the opinions which Mr. Paul-Dubois has expressed, and I could not add anything to them. I think however that I ought to say some words about the comparisons made in the reports, between direct current and single-phase current.

As you know, gentlemen, it is only with direct current such as we are all using at present, that is to say, with a voltage of 600 to 800 volts, that it is possible to use a conductor placed near the level of the ground. All other systems, for imperative reasons of safety, owing to the high voltages used, involve the use of overhead lines.

Most of the reporters state, and in this point we cordially agree with them, that the choice of the systems is a question of kind. As Mr. Paul-Dubois stated a little while ago, it would in our opinion be absolutely dangerous, at present at least, to wish to lay down general rules on this subject.

Everybody at present agrees in the statement, that if we compare the two systems, direct current and single-phase current, which seem to be the most likely to become general, we find in the first place that as regards capital outlay, the fixed installations (leaving out of consideration for the moment the production of the energy and its transmission to the lines themselves) are as a rule cheaper in the case of single-phase current than in that of direct current, while on the contrary the rolling stock costs much more in the case of single-phase current than in that of continuous current.

From the latter point of view I find the expectations of the reporters very optimistic as regards single-phase current. They speak of a difference of 10 per cent; I think it is much greater.

One can hence at once conclude that if the density of the traffic is very great, direct current will probably be the most economical solution from the point of view, be it understood, of the capital outlay; and that the contrary will be the case if there is but little traffic.

We have been curious enough to investigate with what traffic the capital outlay is equal, naturally in a definite case, and we have to state that this traffic-limit varies with the mean power required per ton-kilometre conveyed, that is to say with the conditions of the profile, and even to a certain extent with the speed. In the case of a profile where the down-gradients do not exceed, as a rule for the speeds considered, the equivalent up-gradients — and this applies to nearly all our great French lines — it may be stated that this equality becomes established with an hourly traffic of 200 ton-kilometres (122 English ton-miles) in either direction, that is to say with a total traffic of 6,000 to 8,000 ton-kilometres (3,670 to 4,900 English ton-miles) in the two directions per average working day. The more difficult the profile of the line, the more the direct current becomes advantageous, owing to the necessity of increasing the power of the motors, the weight and the price of which increase much more rapidly with single-phase than with direct current.

It has to be noted, moreover, — and this is rather interesting — that any development of the traffic will as a rule involve less outlay with direct than with single-phase current; and I think that the traffic on all our systems, or nearly all, is developing.

As regards working expenses, it is equally found that single-phase current is above all advantageous on the lines with comparatively little traffic. In this case again the fixed charges, for staff, etc., are less than with direct current, and the difference between the two systems is the more marked the smaller the traffic. It is evident, for instance, that the less the traffic, the smaller the efficiency of the rotary converters in the case of direct current. The expenditure of energy per useful ton carried is greater with alternating current, owing to the weight of the equipment, than with direct current. It here again follows that if the traffic increases beyond a certain figure, it is direct current which becomes more economical.

We have also established by a series of calculations easy to make that there is approximately equality of working expenses under the conditions when there is equal capital outlay, that is to say when the day's traffic is about 6,000 to 8,000 tons (3,670 to 4,900 English ton-miles) on the average. It is evident, moreover, that the more difficult the profile, the greater the advantage of direct current, as its rolling stock and its motors are much lighter.

Starting from these figures, we have ourselves arrived, a long time ago, at using single-phase current on lines with but little traffic, and on the contrary using direct current whenever there is much traffic, and this we shall continue to do whenever such cases arise.

We shall still have to examine the ad-

vantages and the defects of each of the systems proposed.

If we consider in the first place the fixed installations, we note that the high-voltage systems, the single-phase, the three-phase, even the high-voltage direct, although they make it possible to free the road from conductors near the level of the ground — an interesting feature — yet on the contrary they make it necessary to have poles, supports, etc., for which it is often difficult to find room at large stations, and, in particular, at ours. On the State Railway, we have many 6-foot ways where it would be absolutely impossible to put up poles. Moreover, it is very difficult to fix the conductors in certain tunnels of limited gauge existing on old lines; there are a number of lines where it would be absolutely impossible to use single-phase current because constructive works, certain bridges for instance, are too low.

Alternating current, whether single-phase or three-phase, moreover, makes it possible to have very cheap and very simple transformer installations, while direct current makes it necessary to have very expensive revolving apparatus which require a certain amount of looking after. It has however to be noted that if the sub-stations are suitably arranged they make it possible to reduce (and this in my opinion is very important), if not to eliminate, sudden accesses of load at the power stations, thanks to the use either of accumulators, or of revolving dynamos, as for instance is usual with mining machinery. In any case the system makes it possible to operate with a power factor near unity, and this is possible neither with three-phase nor with single-phase current.

It has been said that single-phase traction involves the use of a low frequency which makes the current supplied by the traction power stations practically useless for other purposes. This in our opinion is a capital defect at a period when railways are developing their electric-light installations as well as other electric station appliances; and this, it must be admitted, is a difficulty with single-phase motors.

Finally, it would be unfair not to say a word about the question of electrolysis, which the use of alternating current eliminates almost entirely. As regards this question, our practice has shown that certain lines which have been in use more than ten years have given no trouble, and I think that the Orleans Railway has also had no great trouble from this point of view.

It should be added that on our lines the running track, which is used as return, is nearly insultated from the ground, as care is taken to have the upper surface of the ballast lower than the top of the sleepers.

As a set off against this trouble of electrolysis in the case of direct current, one must mention the disturbances which alternating current, whether single-phase or three-phase, causes in the telegraph and telephone lines, and these involve a very appreciable capital outlay.

If direct current is used, the rolling stock is much lighter, much less cumbrous and much cheaper than if single-phase current is used. In particular, the automotor cars can be constructed without any need for the main current to enter the body of the car. That is the regular practice in America and also in England, where all the control gear for the multiple-unit

working is placed below the floor of the car. One can hence say that the passenger is in complete safety if the floor is insulating and is incombustible.

The same is not the case with high-voltage current taken from an overhead line. The different overhead-line systems make it necessary to have more or less complicated apparatus placed on the roof of the cars, and the use of high voltages in the rolling stock necessitate very special safety measures which it is possible, which it is perhaps even comparatively easy to take on locomotives, but which it is very difficult to carry out on passenger cars. Moreover, the drivers require more knowledge, and accordingly require more pay, and this is a very important point. In fact I think that electric traction should enable us to have a comparatively ordinary train staff, while if we use high-voltage automotor cars, we are face to face with a serious difficulty from this point of view.

When visiting the fine single-phase and three-phase plants constructed by some of our colleagues, I was struck by the minute precautions taken with regard to the rolling stock on the lines to protect the trains should the trolly wire come down. In fact in nearly all these cases, the roof of the vehicles, if not made of metal, is surrounded by a regular network of metal. That can be seen to some extent everywhere, for instance at Oberammergau and in the installations just made by the Brighton at London. Although certain experiments which have been made proved comparatively reassuring, I find these precautions absolutely justified. But must one then not ask oneself whether the same precautions should not be taken with all the vehicles running on the line; and then one sees to what this would lead, for instance, in the case of international lines electrically equipped. Mr. Paul-Dubois spoke to you of the danger of overhead lines; here is one which I mention to you.

Gentlemen, it would seem that in this discussion and even in the reports, it is agreed to disregard three-phase current. However, very good and very many installations of this kind have been made and I am certain that if one of our Italian colleagues had to draw up a report, he would not have failed to bring before us the results obtained in his country with this system. However the gap which existed has been filled up; an Italian engineer has given us very interesting particulars about the use of three-phase current. As for me, I think we should perhaps be going ahead a little too fast if, to some extent *a priori*, we rejected this solution. Is there in fact a better one? Is there one which gives us stronger motors? Certainly not, and the absence of commutators is a sure guarantee for the working of those motors. Let us not forget, in fact, that the single-phase commutator has until now only worked subject to certain additions, thanks to the use of small devices hardly worthy of what electricians will certainly be able to supply to us in a very short time.

In short, I think that the single-phase motor, as regards the working of the commutator, is not yet perfection and that is a reason against the immediate use of single-phase traction.

Among us engineers, is there anyone who knows about the maintenance of the commutator, I mean the maintenance of

the commutator of a powerful motor? I do not think so. Even in Switzerland, one may say that at this present time there is not a single electric locomotive in regular use. Some are perhaps being tried, but that only during the last few days. We certainly have the trials made on the Seebach-Wettingen line, but these are all isolated cases and practice cannot have isolated cases as basis.

The overhead line is, it is true, a little more difficult to construct; but this has been done so successfully in certain cases and so cheaply, that one may ask oneself whether this is really a sufficient reason for the *a priori* rejection of the three-phase system.

We have been told, very justly, that switches were more complicated. But gentlemen, go to the Simplon and see if the line is more complicated; examine the suspension arrangements and on your return tell me what you think.

The asynchronous motor has it is true the disadvantage of a practically uniform speed, but it has the undisputable advantage of regularity of working. Moreover, it makes recovery perfectly easy. Finally, the combinations already effected for running, cascades, change in the number of poles, etc., already make it possible to obtain a sufficiently large number of different economic speeds. The Simplon locomotives are there to give us full information about this subject.

The Italian machines themselves give us rather complete information, and in this connection one will certainly go much further than has hitherto been the case.

I could easily show you how it is possible to obtain a whole series of economic speeds, all possible graduations in the speed and in the tractive effort, by coupling two or more asynchronous motors.

To sum up, I continue to think that each of the systems has its own field of employment, and that it would be unwise at present for a meeting of such authority as the present, to give too much approval to such and such results which are as yet hardly proved. I think, on the contrary, that the Congress will act wisely if it recognizes the advances made and requests manufacturers and railway administrations carefully to investigate the different systems each time a new application turns up.

I am pleased to be able to record that direct-current installations and single-phase-current installations are already at present very closely related. I mean that certain single-phase motors can work perperfectly with direct current. Still better, their working is even improved, to the point that their power is materially increased. I have quite lately had the opportunity of making comparative trials with a well-designed single-phase series motor, with a commutator working well, even with single-phase current, at least during the trials; and I can state that the ratio of the power, monophase to direct, varied between 1 and 1·30. That certainly is a proof of the benefit of using direct current.

Those, gentlemen, are the considerations, rather than conclusions, which I wanted to submit to you, and I think that in this I am in complete agreement with my American colleague whose great knowledge of this subject I fully appreciate, but who is unfortunately not present.

In the comparison I have made and in determining my figures, I have, you

understand, considered steam plants in the neighbourhood of Paris.

The President. (In French.) — You have then considered not water-powers, but steam plants, taking into consideration the cost of coal and other accessory expenses of plants in the neighbourhood of Paris.

Mr. Gleichmann. (In German.) — I should like to say a word about some of the points raised by previous speakers. If I have correctly understood them, these gentlemen, and especially the representative of the Russian railways, have expressed the opinion that direct current may be suitable for many railways, three-phase current for others, single-phase current for still others. Now, gentlemen, it is just this diversity which we wish to avoid in our railway service. For what is necessary, what is absolutely necessary, in the railway service, is complete unification. We consider this of such importance that we have directed our inquiries to the determination of what is most advantageous generally even if in individual cases three-phase current would present advantages owing to the possibility of recovering energy. Accordingly we undertook the work of calculating what advantage resulted from such recovery of energy. I have mentioned the conditions which exist on the Bavarian State Railway. The proportion which can be recovered, that is to say the proportion of the energy previously expended, is here so small that the advantage of this recovery is quite subsidiary. I have been surprised to find that Mr. Wyssling's calculations arrived at the same results as mine, in the case of a railway system where one would expect that this advantage would be more marked, in the case of mountain lines such as the Swiss. I was surprised to find that there also the result was not more than 4 per cent.

And then again, if we wish to recover this energy, it is important, especially from the point of view of technical working, to provide for the possibility of a break in the distributing line, for instance by the use of an automatic cut-out. Let us assume that a heavy goods train is running down the St. Gothard line, with recovery of energy, and let us assume that the circuit is suddenly broken; the train will very soon attain such a speed that it will no longer be possible to check it. It is just from the point of view of operation that we have been led not to attach so much importance to the advantage resulting from the recovery of energy.

Another thing. It has been said that much more experience has been gained with three-phase current and that it is just in Switzerland that there are three-phase installations. I will answer that it is then very surprising that the Lötschberg railway, which is a very characteristic mountain line, on which energy might be recovered, has not thought of using three-phase current, even at the entrance of the two railway lines in the Brieg joint station, the terminus of the Simplon line which is operated with three phase current.

It has also been remarked that according to my report, the operation of the Grosslichterfelde suburban line shows that the consumption of direct current there is better than in the case of the Hamburg-Altona line, where single-phase current is used. Yes, gentlemen, the administration of the Prussian State

Railway carefully considered matters before arriving at a decision concerning the Hamburg-Altona line. It had had long years of experience of operating the Grosslichterfelde suburban line and the figures which I have quoted precisely show that single-phase current is more advantageous than direct current. I will request you to recall the figures which characterize the nature of the lines. The line from Grosslichterfelde to Berlin is 9·5 kilometres (5·9 miles) in length and that of Altona a little more than 26 kilometres (16·2 miles). Hence it is a question of a much longer transmission, and if direct current had been adopted for the Altona line, there would have been greater losses in distribution. At Grosslichterfelde the power station, supplying direct current, is next to the railway; the distances are insignificant. But matters are quite different if it is a question of electrifying very long railway lines. In this case single-phase current has one very marked advantage, namely economic transmission to a great distance, not to speak of the simplicity of the transmission. We have also to consider the figures representing the heights of the stations; on the Grosslichterfelde suburban line, the steepest gradient is 6 6 per mil, and the difference in level of the termini stations is 0·4 metre (1 ft. 3 3/4 in.); while on the Hamburg-Altona-Blankenese line, this difference is 32 metres (105 feet), and the steepest gradient is 12·5 per mil. The Grosslichterfelde-Berlin line shows a consumption of 33·5 watt-hours per ton-kilometre (54·78 watt-hours per English ton-mile), while that on the Hamburg-Altona line is 38 (62·14 watt-hours per English ton-mile). A little reflection accordingly shows the latter line, given the great difference in hight, works under much more economic conditions than the direct-current Grosslichterfelde line.

We attach no importance to the advantage which the three-phase current presents of making it possible strictly to adhere to the time-tables. On the contrary, we think that the property of three-phase current, of keeping the speed uniform, is very disadvantageous, and that for the simple reason that lateness may occur, and once it has set in it is very difficult, with three-phase current, to make up for lost time, and the difficulties multiply. But if one has a motor such as the single-phase motor, which makes it possible to increase the speed, one is satisfied. Our time-tables are so arranged that we can really only make up time on up-gradients, and if we then have available a motor which allows us to increase on up-gradients the speed otherwise reduced, this is an advantage the importance of which it would be difficult to exaggerate.

If I understand Mr. Mazen correctly, he has objected to the single-phase collector, stating that it complicates conditions. With a high frequency, it is certain that resistances are still necessary in the commutator; I have mentioned this fact in my report. I have shown by means of a sketch how the resistances are interposed between the armature winding and the commutator segments (see p. 69 of my report [1]). But the frequency of 16 2/3 periods was decided on precisely because

(1) Vide *Bulletin of the Railway Congress*, March, 1910, p. 1081.

it made it possible to have a motor without these resistances, which runs without sparking and as smoothly as a direct-current motor working at 1,000 volts. The experience gained in the construction of direct-current motors could be taken full advantage of in designing single-phase motors. As regards this point, I find myself in agreement with my colleague Mr. Wyssling, although we did our work quite independently of each other, and we are hence led to propose to the meeting to select, in accordance with our conviction, single-phase current as being that kind of current which combines most advantages. However, we do not wish to dispute the advantages of the other kinds of current. But owing to the simplicity of construction, we think that in our opinion we must in all cases give the preference to single-phase current.

It is certainly not easy to induce a great meeting such as the International Congress to express an opinion of this kind. But it would already be a great step in advance if we recognized that thanks to single-phase current the question has made considerable progress, and if we said that in the present state of technical science single-phase current is that kind of current which is most suitable for electric traction on a large railway system with a difficult train service.

Mr. Wyssling. (In German.) — All the different properties mentioned as being particular advantages of the direct-current system and all the different properties enumerated by the previous speakers in favour of the three-phase system certainly exist. We have neither neglected them, nor lost sight of them in our investigations. But in coming to a decision, it is not a question of enumerating these different properties, but one of working out the relative importance of the different advantages and disadvantages. Now one does not arrive at this result merely by drawing up schemes for equipping a given line and by taking into consideration the results given in this case by each of the systems. I will not detain you long enough to show you in detail that many of the points mentioned during discussion have been examined and refuted in my report, among others. I will refer you for this purpose to my report, which unfortunately appeared rather late.

I will emphasize several points. There is not much left, for Mr. Gleichmann has already dealt with several points about which I proposed to say a word.

As regards, for instance, that property of three-phase current which favours the recovery of energy, this exists beyond dispute and there are cases where it can exercise a decisive influence. Thus on special mountain inclines with long gradients of equal inclination, recovery will perhaps be an advantage. I have also quoted, in my report, the case when it will not be necessary to pass to another system. But as regards the case which we are considering here, namely the main railroads, long lines with a moderate amount of traffic in some places, and with a very heavy traffic in others, other results are arrived at. Even if one can economize such and such a percentage in the case of any one train, that only represents very few per cent of the total energy the power station has to supply, and that even under the most favourable conditions, in such a case for instance as the Burgdorf-Thun line, with

its steep gradients; consequently the total result is hardly affected.

It has also been said that single-phase locomotives cost more than direct-current or three-phase locomotives. That is quite correct. But in drawing up a whole general scheme one finds, as the single-phase system makes it possible to use materially higher voltages in the overhead line, that the distribution installations, the sub-stations, the transformer installations become, taking them altogether, much cheaper than with three-phase current, and still more so than with direct current, for in this case the substations must be closer together; and the reduced expenditure which results much more than counterbalances the greater capital outlay on rolling stock, even with heavy traffic. We have worked out such a calculation for the case of the St. Gothard, taking as basis a time-table with a sufficiently large number of trains. It goes without saying that the difference is still less with a still heavier traffic.

It has also been stated that three-phase current is preferable for other purposes, for instance when it is a question of the joint use of the power stations by the railways and by private industries. We think that it is not advisable to attach much importance to this particular point. The proportion of the power supplied by the different power stations, which is wanted for the railways, is so great that it would be much simpler to have special generating sets in the power stations for supplying the railways, at least as far as turbines and generators are concerned, and to add other sets for the other purposes, if the same water-power is also to be utilized for these other purposes. One will adopt this practice all the more readily, as my experience shows that there is every tendency to keep the traction and the other services separate; at most there will be an additional reserve set. There is absolutely no other disadvantage in this separation and hence it is not of much importance. Station lighting, which has also been mentioned, is a vanishing fraction as compared with the large consumption of energy for traction.

It has been said that the comparisons made were based only on calculations. I admit it, I am of opinion that schemes worked out with care, which refer to the same railway and consider exactly the same time-table, when worked out for different systems, are more useful, particularly if in the case of working expenses the results obtained on other electric lines and other railways are taken into consideration, than a comparison of the working expenses of electric railways of different systems in actual operation. The differences, in fact, between the working expenses of different electric railways working under different conditions are sometimes greater than the differences between the working expenses of steam traction and of electric tractiou. To sum up, I think that a calculation worked out with care will give a more exact idea than the compilation of figures obtained under such and such conditions in cases of electric traction.

That is a summary of what I wished to say. I will conclude by a reflection similar to that expressed by Mr. Gleichmann. With us, it is a question of agreeing as nearly as possible on a system which is suitable in a general way for main railroads, and not of emphasizing

the advantages of the different systems in given cases, advantages which certainly exist, in sometimes using direct current and a third rail in a case of heavy traffic, and in other cases, that of mountain lines, in using three-phase current. But that is not the question; the question is that of determining, as far as possible, the best system for the average conditions existing on main railroads, and I think that as regards this point one can but accept the conclusions enunciated by the three reporters.

Mr. Hruschka. (In German.) — I venture to make some more remarks about the different points raised.

In the first place, as regards three-phase installations in Italy, which as we know work exceptionally well and the good technical and economical results of which are undisputed, we know we have to note that all these lines (thirteen main lines) for which parliament has given concessions are short mountain lines, which would also be very suitable for direct-current operation. But we have been unable to ascertain from anybody whether the Italian engineers have decided that this system is the best for ultimate extension to the whole railway.

In the second place, it has been emphasized that vehicles with three-phase motors can be put togheter in one and the same train and worked together without any inconvenience. I very well know that this can be done with the most recent machines, and that it is even possible to obtain very good adjustment; but it is not possible to have three phase motors working together having a different number of poles, unless they can be arranged so as to work with the same number of poles; while in the case of single-phase current, the fastest and the slowest motors can be used together without disadvantage.

I also wish to remark that I do not very well understand the statement that with a total tonnage of 6,000 to 8,000 tons per day and upwards, direct current is more economic than single-phase. For the inferiority of the direct current consists above all in the fact that it is not possible to transmit large quantities of energy at a low cost, and so I am of opinion that the greater the number of the trains and the heavier the traffic, the greater the line losses must be, the greater the number of more or less costly sub-stations which have to be constructed and operated. To speak plainly, the statement I have just mentioned is opposed to calculation and to known facts.

In the fourth place I will say that the recovery of energy, which I forgot to mention in my speech today, gives, it is true, considerable percentage advantages on certain gradients, but my calculations show that these are insignificant as regards the whole Austrian railway system. For the whole railway system, this advantage with us amounts to very few per cent. I think that the recovery of energy is only advantageous when it is a question of steam plants, where coal and oil can then be saved; with water plants there is no economy, but on the contrary the motors become overloaded so that the utilization of the weight of the locomotives, so desired by electricians, again becomes incomplete, owing to the recovery of the energy. When hydraulic accumulators exist, this is not of importance; for these few per cent can have no influence on the dimensions of the accumulators.

I will also remark that on goods trains,

as long as they are not equipped with the continuous brake, the recovery of energy will be incompatible with the requirements of the service; now nobody can yet say when continuous brakes will be used on goods trains.

In conclusion, I will confirm what Mr. Wyssling has said for Switzerland: with us also the railways will utilize the total output of power stations, or else the power stations will use a considerable part of their plant specially for producing traction current.

Mr. Van Loenen-Martinet, Dutch Railway Company. (In German.) — We may go on talking for a long time about this question without coming to any agreement. As regards myself personally, I am much astonished to find that anybody here still recommends the direct-current system for long distances. It seems however to me to be clear that the direct-current system is not suitable.

As regards three-phase current, I will simply remark incidentally that the great disadvantage of this system is that the air-gap between the rotor and the stator is only 1 millimetre ($^3/_{64}$ inch). It is unnecessary to explain the importance of this to people who have experience of electric traction on railways. I now come to what I consider the essential point. In reading the reports, I have gathered the impression as if one wished to represent the matter as settled in the case of the single-phase system, and as if the single-phase system such as it exists is suitable for adoption on main railroads. This impression does not agree with the results of our operation. I should like to ask you the following question: what experience have we, in the railway service, as regards main railroads, of voltages such as 10,000 volts with the single-phase system? What lines exist? In Holland we have had a 10,000-volt line in operation since 1 October 1908. On all the other lines the voltage is less. Hamburg uses 6,000 volts, and so does the Brighton line and between 6,000 and10,000 volts there is a great difference. Our line from Rotterdam to the Hague is built like that of Hamburg. As regards the overhead line, we profited by the experience gained on the latter railway and if I now tell you that in spite of this we have since January of this year had five break-downs, each of which resulted in a complete interruption of the service lasting from half an hour to an hour, I think that one cannot yet say that this is a satisfactory state of affairs.

As for the motors, I may tell you that we are satisfied enough with them now. The commutators do not give any trouble. I think, particularly if locomotives are used (we have automotor cars), that the difficulties will be even less. But my conclusion is that one must not think that the single-phase system, such as it exists today, is sufficiently advanced to enable us to consider it the system of the future for the operation of the main railroads.

The President. (In German.) — Gentlemen, I propose that we adjourn till Wednesday. Between now and then we will try, in agreement with the reporter, to draft general conclusions to be submitted to the section.

Mr. Gleichmann, *reporter*. (In German.) — I am recalled to Germany by my administration in consequence of the opening of the Landtag; I shall therefore be unable to attend the future meetings.

Meeting held 13 July 1910 (morning).

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The President. (In German.) — We will resume the discussion of the subject of electric traction; we shall have to draw up our conclusions about it. I call upon Mr. Mazen, who wishes to address the meeting.

Mr. Mazen. (In French.) — I only have a few words to say to you.

I have carefully examined Mr. Wyssling's report of which I received a proof; all the tables are still given in German and this, I must say, has given me a little trouble. This examination, and the examination of the other reports presented, have shown me that at present the total number of single-phase locomotives in use in all Europe is:

Switzerland, 0; Germany, 2; Austria, 0. Moreover, the two German locomotives are experimental locomotives on the Oranienburg line, and work with 25 periods, not with 15 or 16 $^{2}/_{3}$ periods.

In Switzerland trials have been made, it is true, on the Seebach-Wettingen section, but those trials have ceased.

I was much surprised by this result when my eyes fell on a prospectus of the *Allgemeine Elektrizitätsgesellschaft*, a prospectus which was sent to all the members of the Congress. I have there found again the two Oranienburg locomotives, both with 25 periods, one of 1,400 and the other of 600 horse-power; I have there seen mention of quite a number of other machines which are being constructed, most of them for mines, a few only for some railway or other; but I find that in reality the number of locomotives in use is only that which I have mentioned; at least I have found no others. That then is the experience we have had in Europe with the single-phase system.

It is true that in America a certain number of single-phase locomotives has been in use on three lines, but Mr. Gibbs, whose report I have read very carefully, states likes ourselves that his opinion on this subject is not at all settled.

The figures we have been supplied with, concerning the single-phase system, are very interesting and we are grateful to those who have brought them to our notice, but these figures are the results of schemes and projects, they are not results of actual applications and we could oppose them by other figures equally based on hypotheses. We ourselves have made investigations which perhaps you would find interesting, but which we prefer not to submit to you now and above all not to discuss at this moment, for it seems to us that the Congress should occupy itself with projects which have been realized, with things proved in practice, and not with anything else.

Such practice we find already realized in the case of direct current and even in that of three-phase current. In any case we do not intend to declare ourselves in favour of either, or in favour of the single-phase system. As far as I myself am concerned, I have successively used all the three systems, according as the one or the other appeared most suitable for the line I had to equip. Hence in this

sense I am above all suspicion. But it would seem to me absolutely dangerous for the Congress to approve by any conclusion, even the results already obtained with direct and with three-phase current, just as it would be dangerous for it to extol the single-phase system.

In one word, we ask you not to pronounce at the moment in favour of any system. No doubt some are comparatively well known, but none can be applied in every case, none is a universal panacea, neither the single-phase nor the direct nor the three-phase; as I stated yesterday, each system has its own field of employment.

Let us accordingly limit ourselves to recording the general progress made. We have fought enough in behalf of electric traction to have the right to say in all sincerity that at the present moment there can be no question of the general electrification of railway systems. Such a transformation cannot enter our ideas. We are still in position of making general investigations and of making particular applications in which the choice of system must be left absolutely free, because it is a question of applications which do not extend beyond one railway system, which do not extend beyond even a small part of a railway system. We ourselves have great schemes, greater schemes than perhaps can be considered here; but as yet there are only schemes applying to small parts of our railway system.

The steam locomotive, gentlemen, is not yet dead. Let us give electric traction the time to become developed before we try to set bounds. To set bounds now, would to be presume too much and to risk strangling it rather than developing it. (*Approval.*)

Mr. Wyssling, *reporter*. (In German.) — I will simply answer this to the remarks made by the previous speaker. The three reporters, who agree with us as to the advantages of the single-phase system, recognize absolutely that up to the present there are comparatively few single-phase locomotives in use, although probably the reporter for America might state that there powerful single-phase locomotives have been in use a long time. As regards single-phase locomotives in Europe, they are not only projects, but some have actually been in use for five years, and at present about a dozen are being built. These gentlemen yesterday had an opportunity of seeing one at the Oerlikon Works. Hence matters are not quite as stated.

We absolutely do not dispute that three-phase current and direct current have given excellent results, or that either the one or the other can today be used for traction on main railroads. We have thought that the International Railway Congress should go beyond this, that it should consider the future and take into account the interests of the countries which are starting on the general electrification of their railway system. Conditions everywhere are not the same. I can understand very well that they may be different in France. In Bavaria, in Switzerland, and also in Prussia, but more especially in the two former countries, the general electrification is studied owing to the water-power which are available. It is a question of marking the way for the future.

This is the first time that I have had the honour of addressing railway engineers, but I think that they also will think of the future and do not wish to raise obstacles against themselves. Now that future is to be found in a certain uniformity. Three of the reporters are unanimously of opinion that under average conditions, the general conditions obtaining on main railroads, single-phase current is the system which will become general. We thought that we should elucidate this question here before the Congress, for the benefit of countries which will now have to come to a conclusion. There are countries in which one line is electrified in one way, another in another. This cannot be so everywhere; there are countries where it is really necessary to come to a decision. We are convinced that the future belongs to single-phase current and that it would be advisable to adopt that system. Some members of the section think the question is not ripe enough for a definite solution. In order to reassure those who live in the countries where it is necessary to come to a decision, the three reporters ask the meeting at least to record that they agree about the conclusions they have proposed. These conclusions have not been read, they have been handed to the President, but we have seen that one could not come to an agreement. I will ask for the insertion, in the minutes, of the conclusions proposed unanimously by the three reporters, in the form laid by me on the table.

The President. (In French.) — I now ask the section if it thinks it advisable to authorize the insertion in the minutes that the three reporters, Messrs. Wyssling, Gleichmann and Hruschka, havea greed to joint conclusions which I will read to you presently. It seems to me that such a request cannot be refused. Before coming however to any agreement in what form we are, on the one hand, to record the opinion of the three reporters, and on the other, that of the sections, I think that we may hear some more of our members.

Mr. Brain, New South Wales Government Railways. — I agree with the view of the three reporters that it would be desirable to adopt, if not a universal system, at least one which would meet with all ordinary railway requirements. This result is very desirable for the sake of uniformity, in order to permit the interchange of rolling stock and to facilitate the construction of all parts of the equipment The conclusions of the reporters show that they have confidence in the monophase system for railways generally.

The President (In French.) — The word "*confidence*" perhaps sums up the whole discussion; but we cannot make this confidence the conclusion of the whole Congress.

Mr. Brain. — The point which I wish to make clear is that while there are a number of examples of monophase railways, of the class known as light railways, and one apparently successful example of heavy goods service, there is, I believe, not one case of rapid, heavy suburban service. The class of service to which I refer involves frequent trains of a number of carriages, with short distances between stops, and very high acceleration. There are many such services working

successfully with direct current. The electrification of such a line, with the additional difficulty of heavy grades, is now being considered in the State whose railways I represent here, and therefore I am anxious to know whether a monophase railway can be instanced upon which such a service is maintained with accelerations, in regular working, comparable with the best direct current practice, — say 1 metre (3·28 feet) per second per second or thereabouts.

Mr. Solacroup, Orleans Railway. (In French.) — A little time ago I asked for leave to speak. in order to say just what the President has now said, better than I could have done so. It is evident, in fact, that confidence does not justify the adoption of a conclusion. I have been attending the meetings of Congress for twenty-five years. and I have always admired with what wisdom, not only the Congress as a whole, but also the individual sections, have refrained from giving advice for the future. One has always limited oneself to recording results achieved; sometimes one has tried to reconcile results obtained on different sides, but one has refrained from giving any opinion as to the future.

I think that this is a very wise practice and that in the present case there is no reason whatever for departing from this practice.

Mr. Loch, Prussian State Railway. (In German.) — A well-known fact, which has been repeatedly published in the papers, is that in 1903 the administration of the Prussian State Railway made trials with 25-period single-phase current on the Niederschöneweide-Spindlersfeld line, near Berlin. In consequence of the information collected, it was decided to electrify the interurban Hamburg-Altona line. This railway has been in operation for several years and has given exceptionally favourable results. The conclusion is drawn that the single-phase current would be most suitable for general adoption in the railway service.

On the experimental Oranienburg line, which is a small circular railway 1·75 kilometres (1·09 miles) in length, experiments have also been made with locomotives: the first single-phase locomotive of the *Allgemeine Elektrizitätsgesellschaft* is in use there, during twenty hours per day, with short interruptions. The results have been so satisfactory that the administration of the Prussian State Railway has decided to extend the application of single-phase current.

At present the Bitterfeld-Dessau line is being equipped; it will be finished in autumn and on it through trains will be hauled by single-phase locomotives. It was Mr. Wittfeld, of the Prussian Board of works, who fixed the chief details of the construction of the locomotive and of the equipment of the track, by agreement with the chief German electro-technical firms. It was decided to use single-phase current with 15 to 16 $^2/_3$ periods and to start with two types of locomotives; one for express trains and one for goods trains. A certain number of them have been ordered for immediate needs and it is intended to use these at once. On the Prussian State Railway, one hopes with every confidence that single-phase current will prove the current of the future.

The President. (In French.) — The delegate of the New South Wales Govern-

ment Railways has asked whether there were any applications of single-phase current in which an acceleration of 1 metre (3·28 feet) per second per second had been attained. I do not think that we should occupy ourselves with such question of detail. Delegates who are able to answer this question are requested to give their answers to Mr. Brain direct; but I cannot open a discussion on such a point. (*Signs of approval.*)

Mr. Merczyng. (In French.) — I wish to make a short remark.

In Mr. Wyssling's very interesting report I find no mention of the experiments made in Sweden. I may mention that at Stockholm I have seen a line operated with single-phase current and I know that the main line Kiruna-Riksgrenze will be electrified over a length of 130 kilometres (81 miles); at all events the schemes are completely worked out. If there are any Swedish delegates among us, they could no doubt supply us with more detailed information, but I have in any case thought it useful to mention these very important facts.

Mr. Hruschka. (In German.) — I wish, briefly, to remind you that the conclusions in favour of single-phase current result from investigations which have extended over the following periods of time: Switzerland, five years; Austria, four years; Sweden, two years; and that Austria and Hungary are having a certain number of single-phase locomotives built of a power varying up to 1,000 horse-power. As regards the question of confidence in the single-phase system, it is in every way important to see that this confidence is justified to a certain extent by long years of investigation and by numerous practical applications.

The President. (In German.) — Gentlemen, the three reporters have drawn up a set of conclusions, and they ask the section to authorize their insertion in the minutes, but without the section thereby signifying their agreement with the conclusions. These are the conclusions in question :

" 1° The kind of current must not be selected on account of its suitability for several isolated lines, but in taking into account its application to whole railway systems ;

" 2° The introduction of electric traction makes it possible to effect considerable savings as compared with steam traction, particularly if storable water-power is available. By introducing electric traction the traffic-capacity can be increased without any extra expenditure for track work ;

" 3° The single-phase current is the kind of current, in the present state of science, which is best suited for traction on main railroads. In certain cases, the direct-current and three-phase systems have shown that they can also suit all such circumstances ;

" 4° In the case of single-phase current the most favourable number of periods seems to be from $^{40}/_{3}$ to $^{50}/_{3}$, and the voltage admissible in the conductor, from 10,000 to 15,000 volts."

Mr. Ernest Gerard, *vice-president.* (In French.) — I do not see any objection to recording in the minutes that three reporters agree as to these conclusions, but I ask myself whether it is not advisable to mention that the fourth reporter, Mr. Gibbs,

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has expressed doubts thereon and has, in fact, not expressed any opinion in favour of any definite system.

The President. (In French.) — I think, however, according to what I have been told, that Mr. Gibbs also agrees to accept these conclusions.

Mr. Paul-Dubois. (In French.) — Mr. Crawford could not attend today's meeting and he has sent me a note stating that Mr. Gibbs cannot recommend the adoption of the single-phase system to the exclusion of the others.

Mr. Ernest Gerard. (In French.) — As Mr. Gibbs does not agree with the other reporters, this fact should be recorded.

The President. (In French.) — We can then add that Mr. Gibbs does not agree with the opinion expressed by the three other reporters as far as single-phase current is concerned.

Mr. Paul-Dubois. (In French.) — As far as the exclusive use of single-phase current is concerned.

The President. (In German.) — It does not seem to me that the three reporters exclude the other systems. This is, in fact, what they say : " Single-phase current is the kind of current, in the present state of science, which is best suited for traction on main railroads ".

Mr. Mazen. (In French.) — It is just the words " which is best suited ", which we are discussing. Is it " best suited " in all cases? That is the question. It must not be forgotten that Mr. Wyssling was appointed reporter, not only for Switzerland, but also for all the countries except those dealt with by other reporters. Hence he in a way represents France and Italy, and it is necessary to know whether the Italians and the French agree with him. Now I think I am able to say that this is not so.

Mr. Greppi, Italian State Railway. (In French.) — I was just going to speak about this point. Mr. Wyssling, in his report, has dwelt at length on the schemes which are being investigated, and on what has been done in the country in which we are, but he has said very little about what has been done in France and in Italy. In Italy, we have three-phase installations which have been in operation since ten years and which work very well. Those are facts which should not be lost sight of. (*Hear! Hear !*)

Mr. Wyssling. (In German.) — In the proposals submitted, it is certainly not said that these countries have arrived at these conclusions; we have simply expressed the personal opinion of three reporters. What we desire is that it should be reproduced in the minutes.

The President. (In French.) — The remarks made by Messrs. Mazen and Greppi are well founded, but the three reporters simply ask that it should be entered in the minutes that they have agreed to personal conclusions which I have read out; and it seems to me that this cannot be refused to them.

Mr. Solacroup. (In French.) — I think I must draw the attention of the section to the fact that the procedure proposed is by no means a normal one. The reporters have presented very interesting reports to us and I by no means intend to

dispute that single-phase is the best form of current to adopt, I do not even intend to discuss this point, but I wish to mention that in their reports the three reporters have drawn up no conclusions or else have only drawn up very vague and summary conclusions, and that they come today to us and declare that they agree to draw up common conclusions which they seem to be desirous, in a way, to impose on us. It is this fact which makes the situation somewhat delicate. It seems to me that when reporters have presented their reports their work is finished and that it is for the section itself then to draw up the conclusions.

The President. (In French.) — I think there is a misunderstanding. It is not a question of conclusions, for I will presently propose to you general conclusions which will not only depend on the reports of Messrs. Wyssling, Gleichmann and Hruschka, but on all the reports and above all on the discussion which took place the day before yesterday and today. The point before us at this moment, is simply the insertion in the minutes of the personal opinions of the three reporters based on their investigations and on the information collected in their reports. If the meeting wished to ratify their opinions, that would be all right; but if not, those opinions remain the personal opinions of the three reporters, and nothing more.

Mr. Solacroup. (In French.) — If it is only to a question of such a simple record, I think, in fact, that this insertion in the minutes can not be refused.

Mr. Graftio. (In French.) — Three of the reporters are agreed, but the fourth is not and it is asked that the opinions of three reporters should be recorded in the proceedings of the Congress. It would at least then be necessary that the opinion of the meeting should also be given side by side with the personal opinion of the three reporters.

The President. (In French.) — That is what we are going to do and later on we will agree as to the drafting of a general conclusion; but at present it is only a question of meeting the request of three reporters.

Mr. Mazen. (In French.) — Gentlemen, by very virtue of their appointment, the opinions of reporters have a special authority. They have been charged with investigating a subject; they have received information from the different railway administrations for the purposes of this investigation; they have examined this information at their leisure, which, be it remarked, we have not been able to do. I therefore fear that the opinions which the three reporters have agreed to express, and which would be in contradiction with the more general opinion expressed by the section, may take away all authority from the latter.

Mr. Steinbiss, *vice-president.* (In German.) — As the discussion has arrived at this point, I should also like to express my opinion. I think that even when the general conclusion of the meeting is not identical with that of the three reporters, the latter have a right to ask that their opinion should be made known and that it should be added to the minutes. Hence Mr. Wyssling's proposal should be approved.

Mr. Mazen. (In French.) — If it were only a question of a personal opinion, that would be all right; but it is only in their capacity as reporters that these gentlemen have agreed to a conclusion, and their appointment as reporters gives to this opinion an indisputable authority. The Italian delegates have however just said that they do not agree with Mr. Wyssling, and we say the same. Now Mr. Wyssling is reporter for France and Italy, and one could think that his opinion reflects ours.

The President. (In German.) — The reporters inform me that they have agreed to modify their wording as follows :

" Given the conditions special to the countries considered in the reports (Germany, Austria, Switzerland), the single-phase current is the kind of current which is best suited, etc."

Mr. Mazen. (In French.) — By thus modifying their wording the reporters in a way condemn themselves and we could reproach Mr. Wyssling with having forgotten France, England and Italy. What is done in those countries however is not negligible ! (*Laughter.*)

We also use single-phase in France, and we are preparing to use it still more. Hence, it is not in Germany alone that single-phase is being applied. In reality, the opinion expressed in the three reports applies more to central Europe and not to the Latin countries and England, not to speak of the United States for which a special reporter was appointed.

The President. (In German.) — (*Addressing the reporters* :) The opinion seems to imply that the French and Italian railways, which should however be represented in our statement, are opposed to the phrase " given the conditions special to the countries considered" and find that too much is said. I confess that I have taken this to be so, and I think that it would be wise to come to a compromise. We are face to face with a proposal to read a set of general conclusions in order to see if it is necessary to introduce any modification or to make any addition.

The following, gentlemen, are the proposed conclusions which have been prepared :

" 1° The application of electric traction has made great progress, from the technical point of view, during the last few years, so that it is now recognized that it can give a satisfactory solution for main railroads, in using either locomotives (great speeds and weights) or motor cars "

Mr. Salomon. (In French.) — I would readily agree with this wording if the words " in certain cases" were added. In fact there are certainly cases in which it is impossible, from the economic point of view, to apply electric traction.

The President. (In French.) — I think that our wording will satisfy Mr. Salomon. We then say : " The application of electric traction has made great progress, from the technical point of view, during the last few years " ... that is the hot-water tap (*laughter*), " ... so that it is now recognized that it can give a satisfactory solution ... " that, that is the Indian rubber (*laughter*) " ... for main railroads, in using either locomotives (great speeds and weights) or motor cars."

Mr. Ernest Gerard. (In French.) — It is

in fact a question of recording the progress made as compared with what the Congress recorded in 1905.

Mr. Mazen. (In French.) — I think that all electricians will agree to admit the phrase which Mr. Salomon asks should be added : " in certain cases ". I even think one might say : " in very special cases ".

Mr. Noltein, Moscow-Kazan Railway. (In French.) — It would in fact be better not to generalize, and to say : " in certain cases ".

The President. (In German.) — Gentlemen, do you wish our conclusion to be toned down still more ?

Mr. Herdner, Midi Railway. (In French.) — Let us say : " in certain cases ".

Mr. Ernest Gerard. (In French). — The least we can today do is to adopt a conclusion more affirmative than that adopted by the Washington Congress. One can assert that the practice of electric traction offers us a number of systems out of which it is possible to select one technically applicable in any definite case.

The President. (In French.) — I think it is enough to say : " can give a solution ". If we add the words " in certain cases " we would give a really too vague a character to our conclusion.

Mr. Herdner. (In French.) — That would not be an evil.

The President. (In French.) — Then I consider the proposed wording adopted.

" 2° Sundry systems are in existence and their respective application is a question of kind."

A delegate. (In French.) — Is that all ?

The President. (In French.) — No, there is a third paragraph as pious as the two first. (*Laughter*.)

" 3° The Congress requests railways who make applications of electric traction on their lines to agree as much as possible with each other to take all measures to facilitate the exchange of rolling stock at joint stations. "

Mr. Krasny. (In German.) — During the discussion, I raised the question of an international agreement relating to the essential features of electric traction. I beg to state that the wording proposed for the conclusions seems to me to suffice, for the time being, from this point of view.

The President. (In French.) — Gentlemen, yet another conclusion is submitted to me :

" Seeing the very practical results obtained with the direct-current, the single-phase and the three-phase systems, the Congress expresses the wish that the three systems should be applied by the different administrations. "

Mr. Mazen. (In French.) — I must oppose the adoption of that resolution. Other systems may in fact turn up. Thus several manufacturers have told me that it was proposed to introduce, in single-phase motors, modifications which are great from the point of view of system.

The President. (In French.) — I also cannot support such a conclusion.

Gentlemen, we have now drafted the general conclusions to be presented to the Congress on behalf of the 2nd section. It now remains for us to decide whether we are to enter in the minutes the opinion to which the three reporters have agreed.

I will read out clause 3° of their text :

" Given the conditions special to the countries considered in the reports (Germany, Austria, Switzerland), the single-phase current is the kind of current, in the present state of science, which is best suited for traction on main railroads. In certain cases, the direct-current and three-phase systems have shown that they can also suit all such circumstances. "

Mr. Mazen. (In French.) — I think that what we are asked to do is against the rules of the Congress. For Messrs. Wyssling, Gleichmann and Hruschka are no longer acting as reporters, but as simple members; hence I could equally ask that my personal opinion should be entered in the minutes, and all our colleagues could do the same. What the Congress asks us to do is not to express the personal opinion of such and such a member, but an opinion to which section agrees.

The President. (In French.) — We just have the luck of having among us this morning one whose authority will be recognized by every body, namely Mr. Dubois, president of the Permanent Commission. I therefore think that I may refer to him and ask him to help us in settling the difficulty which has arisen.

Sir, we are at present considering the subject of electric traction. Four reporters had been appointed. Three of them had agreed to common conclusions which were not accepted by the section, but they ask that these conclusions should be entered in the minutes as reflecting their opinion as reporters. Mr. Mazen thinks that such insertion in the minutes would be out of order.

Mr. Dubois. (In French.) — I do not think so.

The President. (In French.) — I am of the same opinion.

Mr. Mazen. (In French.) — Then, in order to be correct, we should add that the fourth reporter represents a country where the opinion of the majority would perhaps by no means agree with that of the first three reporters. Thus it is not the opinion of all the reporters, which we are asked to record in the minutes, but the opinion of three reporters in the capacity of simple members.

Those gentlemen had been autorized to make reports. They have drawn the conclusions they liked. We have examined their reports and their conclusions and we have drafted our own. During the discussion the three reporters, no longer acting as such, but in their own personal capacity, have agreed to conclusions which they ask to be recorded in the minutes. I find that this procedure involves a serious defect : one might think, for instance that Mr. Wyssling, who drew up the report not only for Switzerland, but also for France, England and Italy, had expressed the ideas current in those countries.

There are two alternatives : either these gentlemen are acting as reporters, and then I say that the section has not accepted their conclusions, or else they are acting as simple members, and then if their conclusions are recorded, each of us could equally demand to have his opinion entered in the minutes, and this would be entirely irregular.

Mr. Dubois. (In French.) — The repor-

ters are charged with drawing up reports. If as conclusions in those reports, they express an opinion, that is their personal opinion.

The President. (In French.) — I disagree with Mr. Mazen's opinion, and I think that the personal opinion of the three reporters can be entered in the minutes, but we should add : " the section, after long discussion, could not adopt these conclusions and passed the following conclusions."

Mr. Dubois. (In French.) — The reporters compile their reports from the information they have collected in the countries where they have been asked to make their inquiries. If at the end of that report, they think it right to express an opinion — and all do not do so, many even abstain from doing so — it is very evident that this opinion is a personal opinion and only concerns them. Other members could also ask that their personal opinion should be recorded in the minutes, but this is a question of degree.

Mr. Mazen. (In French.) — I fear that if we proceed in this way we stray a little. We are the delegates of countries which were represented by one of the reporters. Now we do not share the opinions of that reporter and we will be compelled to oppose our opinion to that expressed by him no doubt in his own personal name up to a certain point, but also a little in his quality as reporter.

Mr. Dubois. (In French.) — It has never been considered that a reporter could give anything but his own personal opinion.

Mr. Mazen. (In French.) — We then will ask that it should be recorded in the minutes that in the opinion of the President of the Permanent Commission the reporters only represent themselves, but never the opinion of the countries they have to consider in drawing up their reports.

Under these conditions, their opinion only has the same value as the opinion of any of their colleagues and no longer that which the opinion of a reporter can have. Now that is not what we want.

The President. (In German.) — Gentlemen, I think that Mr. Mazen will be fully satisfied by the formal declaration that the conclusions drafted by the three reporters have not been ratified by the meeting and by the record, in the minutes, of the reservations he has just made.

We have accordingly finished the discussion of the question of electric traction.

Gentlemen, our work is finished. The subjects we had to discuss have all been considered. I now ask you kindly to attend, as many of you as possible, at the general meeting in order to help us to support the conclusions you have adopted.

In declaring your work finished, gentlemen, I wish to thank you both for the zeal you have shows as well as for your indulgence for the way in which I have presided over your discussions. (*Applause.*)

Mr. Salomon. (In French.) — Gentlemen, I think I express the opinion of all of you in saying that it is rather for us to thank our President for the amiability and impartiality he has shown in presiding over our discussions. (*Applause.*)

DISCUSSION AT THE GENERAL MEETING

Meeting held on 15 July 1910 (morning).

Mr. P. WEISSENBACH, president, in the chair.
General secretary : Mr. L. WEISSENBRUCH.
First assistant general secretary : Mr. MÜRSET.
Second assistant general secretary : Dr. A. BONZON.

Mr. Gerstner, *President of the 2nd section*, read the

Report of the 2nd section.

(See *Journal de la huitième session*, No. 10, p. 11.)

" The reporters, Messrs. Crawford (replacing Mr. Gibbs), Gleichmann, Hruschka and Wyssling gave summaries of their reports.

" Mr. Krasny (*Austrian State Railway*) proposed that the Permanent Commission should convoke an international conference in order to fix the fundamental principles of the technical standardization affecting the exchange of rolling stock on the international lines. He also drew attention to the fact that the receipts of electrified railways should be such as not only to cover the working expenses, but also the amortization of the installations and of the rolling stock which became unproductive as a result of the electrification.

" Mr. Wyssling showed that in his estimates he had provided for the amortization of the installations which had become useless as a result of the electrification.

" Mr. Gleichmann made a similar statement.

" Mr. Nicoli (*Italian State Railway*) spoke about the lines of the Italian State Railway at the port of Genoa, which had been or were being electrified. He gave information as to the locomotives, the three-phase system, and the power station, and showed that the electrification had paid, consequent upon the increased tonnage and increased speed of the trains. He mentioned other lines which would also soon be electrified. The single-phase system was going to be tried.

" Mr. Salomon (*French Eastern Railway*)

remarked that it was as yet not agreed which was the best system.

" The PRESIDENT was of opinion that the Permanent Commission should address itself to the governments, so that the latter should appoint an international commission to discuss the unification of the different systems.

" Mr. FLURY (*Swiss Federal Railway*) remarked that as regarded railways an international conference for obtaining uniformity existed. This should have the question submitted to it for discussion, by the intermediacy of the Swiss Federal Council.

" Mr. STEINBISS (*Prussian State Railway*) thought that the Federal Council, on the invitation of a government, could summon such a conference; it was not for the Congress to express this desire.

" Mr. HRUSCHKA (*reporter*) stated that the single-phase system could be adapted to all cases. Single-phase locomotives could run on three-phase and on direct-current railways. It was for the different administrations to agree among themselves as to the best systems.

" Mr. MERCZYNG (*Russian State Railway*) gave some information on the subject of the falls of Russian rivers; their utilization with a view to the electrification of Russian lines was being investigated.

" Mr. JULLIAN (*Midi Railway*) gave some information on the subject of the experimental electrification of some lines of the Midi Railway in connection with the government. The system selected was single-phase, 12,000 volts and 16 $^{2}/_{3}$ periods. The type of locomotive would not be settled till after the trials which were going to be made with several locomotives of different makes.

" Mr. GRAFTIO (*Russian State Railway*) said that it would be dangerous to recommend one given system, for instance the single-phase, as being the only good one. Considerations of an economic character, and of safety in working, might make the selection of different systems advisable in different cases. For instance in the case of two Russian lines, the investigations made had shown that the cost of single-phase would be higher than that of three-phase; in another case direct current with third rail gave the best result. In the case of Russia, there was no question of general electrification, and as conditions varied in each individual case, it was possible to avoid using different systems.

" Mr. PAUL-DUBOIS (*Orleans Railway*) said that at present they only had the results for three-phase and for direct-current lines; those for single-phase were not yet available. A comparison of the figures given in the reports showed that the three systems were equivalent, within a few per cent, as regards prime cost and cost of working. As compared with steam working, the cost of electric working was lower; it seemed to him that the 3 per cent provided for the amortization was too little. He thought that it was as yet too early to decide in favour of any given system, as sufficient experience had not yet been gained.

" Mr. MAZEN (*French State Railway*) declared that he agreed with Mr. Paul-Dubois. He discussed the advantages and disadvantages of the various systems, and

showed that direct current was more economic in the case of very busy traffic. Rolling stock for direct current was lighter and more reliable than that for alternating current. Each system had its advantages under suitable conditions; it was therefore not justifiable for the Congress to decide in favour of any one system.

" Messrs. Gleichmann, Wyssling and Hruschka (*reporters*) endeavoured to refute the statements made by Messrs. Mazen, Paul-Dubois and Graftio, laying particular stress on the fact that it could not be a question, in a general decision, of enumerating the advantages of the different systems, but of determining which system presented, from the economical and the technical point of view, the most favourable solution for the electrification of main railroads. In the opinion of the three reporters, this agreement would also affect the simplification of the international traffic; and the single-phase system satisfied all the conditions involved best.

" Mr. Van Loenen-Martinet (*Dutch Railway Company*) thought that the trials so far made with the single-phase system were not enough to justify its general adoption. As yet one had not sufficient experience of overhead lines with a voltage of 10,000 volts or more.

" Mr. Mazen thought that it would literally be dangerous for an international association to pronounce in favour of any one system of electric traction; as yet, as far as main railroads were concerned, one only had experience of direct and of three-phase traction; the single-phase system was still in the stage of study, project and experiment. In his opinion the Congress could only state that great progress had been made in the matter of electric traction. This progress was however sufficiently important to justify the length of the discussion of the subject. He proposed the rejection of the conclusions of the reporters, and submitted instead conclusions of a general nature, more in harmony with the present state of the question.

" Mr. Wyssling agreed that the resolutions jointly proposed by the reporters should not be submitted to the Congress, but expressed the wish that they should be recorded in the minutes.

" After a discussion in which Messrs. Brain (*New South Wales Government Railways*), Solacroup (*Orleans Railway*), Loch (*Prussian State Railway*), Merczyng, Hruschka, Ernest Gerard (*vice-president*), Paul-Dubois, Mazen, Greppi (*Italian State Railway*), Wyssling, Graftio, Steinbiss, Salomon, Krasny and Dubois (*president of the Permanent Commission*) joined, it was decided, on the proposal of the President, to enter in the minutes the conclusions jointly proposed by the reporters, Messrs. Wyssling, Gleichmann and Hruschka.

" These conclusions were as follows :

" 1° The kind of current must not be selected on account of its suitability for several isolated lines, but in taking into account its application to whole railway systems.

" 2° The introduction of electric traction makes it possible to effect considerable savings as compared with steam

traction, particularly if storable water-power is available. By introducing electric traction the traffic capacity can be increased without any extra expenditure for track work.

" 3° Given the conditions special to the countries considered in the reports (Germany, Austria, Switzerland), the single-phase current is the kind of current, in the present state of science, which is best suited for traction on main railroads. In certain cases, the direct-current and three-phase systems have shown that they can also suit all such circumstances.

" 4° In the case of single-phase current the most favourable number of periods seems to be from $^{40}/_{3}$ to $^{50}/_{3}$, and the voltage admissible in the conductor, from 10,000 to 15,000 volts."

" The section could not however fully agree to these conclusions; it accordingly decided to submit the following conclusions to the general meeting."

The President. (In French.) — The following are the

CONCLUSIONS.

" 1° The application of electric traction " has made great progress, from the " technical point of view, during the last " few years, so that it is now recognized " that it can give a satisfactory solution " for main railroads, in using either locomotives (great speeds and weights) or " motor cars.

" 2° Sundry systems are in existence " and their respective application is a " question of kind.

" 3° The Congress requests railways " who make applications of electric traction on their lines to agree as much as " possible with each other to take all " measures to facilitate the exchange of " rolling stock at joint stations."

— These conclusions were adopted by the general meeting.

APPENDIX

[621 .33 (.45)]

Note on the electrification of the old Giovi line on the Italian State Railway.

Some few months ago the Italian State Railway completed the electrification of the old Giovi line, and the first trials have been made with complete success in all technical respects; this line will now at once be opened to traffic.

It is our intention to give the complete results of working at a later date, but in the meantime it appears to us that it would be of use to give some brief particulars relating to the different portions of the installation.

This new application of electric traction is one of special importance, both on account of the profile of the line and also on account of the extraordinary density of the traffic.

On the Pontedecimo to Busalla section (about 10·5 kilometres [6·5 miles] in length) of the old Giovi line, there are long gradients of 28 to 35 per mil in the open and of 29 per mil in tunnels, together with curves of 400 metres (20 chains) radius.

The application of electric traction was decided upon in order to increase the carrying efficiency of this line, which, in consequence of its gradients, was previously extremely limited.

At present the new system of traction has only been applied to the Pontedecimo and Busalla section, but electric trains will shortly leave the shunting yard at Campasso and later still they will leave from the Genoa-Brignoles station.

The programme of traffic which served as a basis for the scheme was as follows :

Each train consisting of twenty-one wagons of a mean weight of 18 tons (gross weight including load, or 380 tons in all) is worked by means of two electric locomotives, the one at the head and the other at the tail of the train.

The trains will follow each other at fifteen minute intervals, but if increase in the traffic requires it, this interval may be reduced to ten minutes over the normal working period of eighteen hours, which in times of necessity may be increased temporarily to twenty hours per day.

With a working coefficient of 70 per cent, which has been determined by numerous trials made when working the heaviest

traffic by means of steam locomotives (this is a minimum in the case of electric working, which admits of greater regularity), the number of wagons which can be sent daily over the old Giovi line is as follows :

	For 18 hours.	For 20 hours.
At 15 minute intervals	1,058 wagons.	1,176 wagons.
At 10 — —	1,587 —	1,764 —

If to these be added the 1566 wagons which represent the maximum traffic possible under regular service conditions on the line which supplements that of the Giovi, the total daily vehicles will amount to more than 3,300 on the Genoa-Ronco section common to the lines connecting Genoa with Milan and Genoa with Turin.

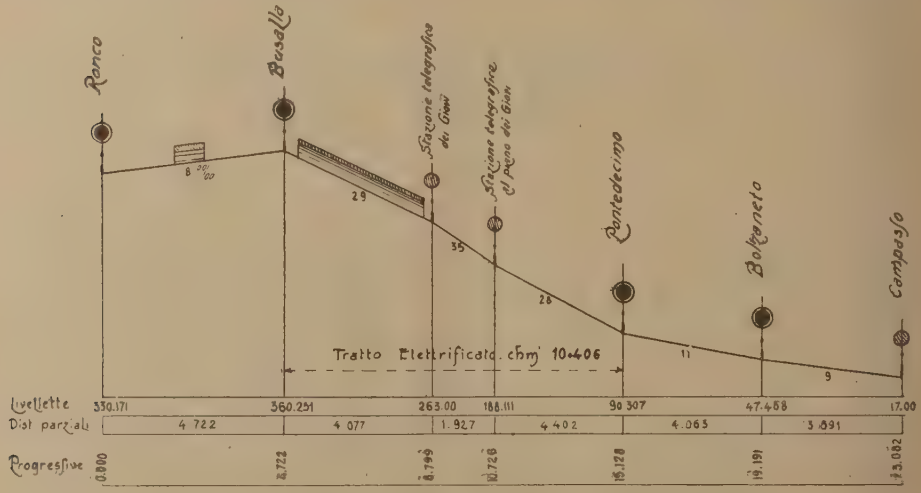


Fig. 1. — Profile of the Ronco-Campasso line. — Double track.

Explanation of Italian terms : Dist. parziali = Portions of the distance. — Livellette = Levels. Progressive = Total distances. — Tratto elettrificato chm = Electrified section.

The trains of empties returning are trebled on the down grades.

The electric equipment has been modelled on that which is working on the Valteline line (Lecco-Colico-Sondrio-Chiavenna), which answers the necessities of railway traction, that is to say, a three-phase system worked at high voltage and with low periodicity both in the primary transmission line and on the contact wires.

The asynchronous polyphase motor (or Ferraris motor) which gives a practically constant speed independent of the load, has been found best to meet the conditions of the case under consideration, in which it is a question of a line with nearly uniform gradients.

I

Steam generating station.

As there are no waterfalls capable of supplying a central hydraulic power station in the vicinity of the line, and since it

is necessary that there should always be a reserve of power supplied by a central steam power station, it has ben thought preferable to equip the electric generating station with steam plant entirely. The « Chiappella » quarry, which is situated almost in the harbour at Genoa, has been chosen as the site for this generating station in consequence of the ease with which the coal supply can be arranged for and of the possibility of using sea-water for the condensers.

The installation at present only consists of two turbo-alternator sets, one of which is used as a stand-by; each set is capable of developing a normal power of 5,000 kilowatts, which correspond to a maximum output of 6,250 kilowatts continuously and of 10,000 kilowatts under intermittent load. These turbo-alternators are supplied from a battery of seven boilers, one of which is a stand-by. The products of combustion are led into a chimney with an inside diameter of 3 metres (9 ft. 10 in.) and a total height of 78 metres (256 feet) above the firebars.

The installation of two other similar generating sets of the same power has been arranged for with a corresponding battery of boilers and accessories, so as to enable three generating sets to be kept working simultaneously, with the fourth as a stand-by. The coal, which is brought by lighters to the Biagio Assereto quay, is conveyed direct to the boilers by means of a coal conveyor and coal bunkers.

The cinders are taken away by conveyors also, while the gaseous products of combustion pass through two groups of Green economizers placed behind the battery of boilers; in these the temperature of the feed water is raised 50° C. (90° Fahr.); the quantity of water required is from 30 to 40 cubic metres (1,060 to 1,410 cubic feet) per hour. The water, from the aqueducts of the town of Genoa, is received in large tanks having a capacity of about 5,000 cubic metres (176,600 cubic feet), placed below the boiler-room and forming a reserve in case of any interruption in the water-supply.

Each set of turbo-generators installed in the engine room consists of a Westinghouse-Parsons turbine directly coupled to an alternator generating three-phase current at 15 periods and 13,000 volts difference of potential between two phases. The turbo-generators are run at a speed of 900 revolutions per minute, irrespective of fluctuation in the load, this being effected by means of an extremely sensitive governor.

The steam turbine is of the reaction type, consisting of a cylindrical stator into which the steam is led, and after acting on the rotor at the centre of its length, is subjected to successive expansion through two series of rings with blades, and passes to the exhaust on both sides, thereby producing a natural condition of perfect equilibrium in the moving masses as well as the elimination of all end-thrust along the axis of rotation. Special valves regulate the admission of steam at different loads.

The armature of the alternator is fixed and the field magnets revolve, thus forming a very efficient fly-wheel. The armature is normally excited by a 50-volt current produced by an exciting dynamo carried on the main shaft of the generating set; it can, however, be excited by an independent exciter. The Tyrill governor automatically maintains a nearly constant voltage under different conditions of load.

The switchboard is operated by means of relays and is fitted with two groups of bus-bars, of three conductors each; there is also, besides the normal apparatus, an electric controller which acts on the governors of the turbines in order to facilitate putting the alternators in parallel.

As the three-phase motors on the locomotives generate current when they are driven at a speed greater than that of synchronism, and this is returned into the supply line, the central station is provided with a fluid resistance for converting any surplus of energy returned into heat. This resistance is automatically thrown into circuit by a relay fitted in the generator circuit.

II

Transmission of power. — Conductor lines and transformer sub-stations.

The electric energy generated at 13,000 volts by the generating sets at the Genoa generating station is led by means of two primary conductors to the four static transformer sub-stations at Rivarolo, Pontedecimo, Montanesi and Busalla, where the voltage is reduced from 13,000 volts to one of 3,000 volts (triangular). Each of the two primary transmission lines consists of three copper conductors 8 millimetres ($^5/_{16}$ inch) in diameter, carried on porcelain bell-shaped insulators supported on lattice poles; the latter are secured to the ground by bolts bedded in concrete foundation blocks.

From the northern end of the Campasso shunting yard as far as Busalla, the poles are used to carry the primary conductors and also the supply line. Generally they are placed 50 metres (55 yards) apart. This distance is increased to a maximum of 70 metres (76·5 yards) at some few places.

Between each pair of lattice poles is placed a third pole of Mannesmann tube of small section used as an intermediate support for the supply line, with the object of reducing its lateral oscillation.

Between the two stations of Montanesi and Busalla, a third three-phase line at 13,000 volts has been carried through the tunnel. A transverse suspension system has been adopted for the supply line with a view to the facility it affords for carrying the line through tunnels.

This transverse suspension system is arranged by means of steel wire insulated from the supports by porcelain spheres and supporting each of the supply lines by means of two insulators.

There is quadruple insulation between two phases and triple insulation between the wires and the earth.

Two of the three phases of the contact or supply line are installed as overhead conductors (each one consisting of two wires of hard copper, each 8 millimetres [$^5/_{16}$ inch]) in diameter, while the third is formed by the rails, which are bonded together by special electric bonds. Moreover, the four rails are electrically connected with each other every 500 metres (547 yards) by means of a transverse copper connector.

In the tunnel the transverse steel suspension wires are replaced by manganse-copper wire and the metallic portions of the insulators are made of bronze.

In the transformer sub-stations one room contains the transformers, one contains the 3,000-volt switchboard, and two others contain the section switchboard and the high-tension switches for the 13,000-volt supply.

At each transformer sub-station are installed four single-phase oil-bath transformers each of 750 kilovolt-amperes without special cooling arrangements. Three transformers are arranged in triangular connection to the line conductors; the fourth is used as a stand-by.

The installation of the suspension for the two overhead lines working at 3,000 and at 13,000 volts respectively was effected by means of a special train fitted with tools operated by compressed air

Fig. 2. — Engine room.

Fig. 3. Leblanc condenser.

Fig. 4. — Boiler room.

Fig. 5. — Coal conveyors.

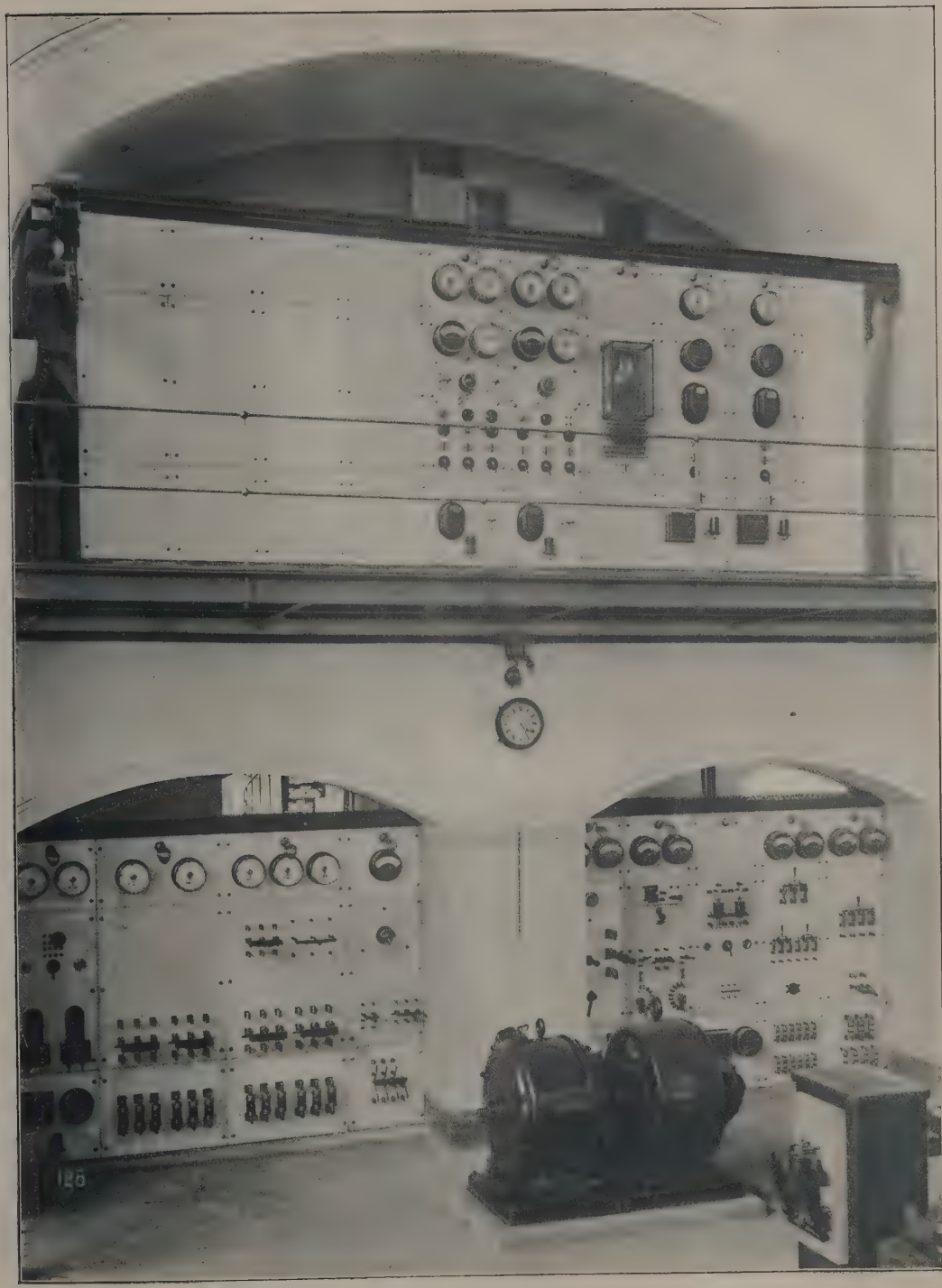
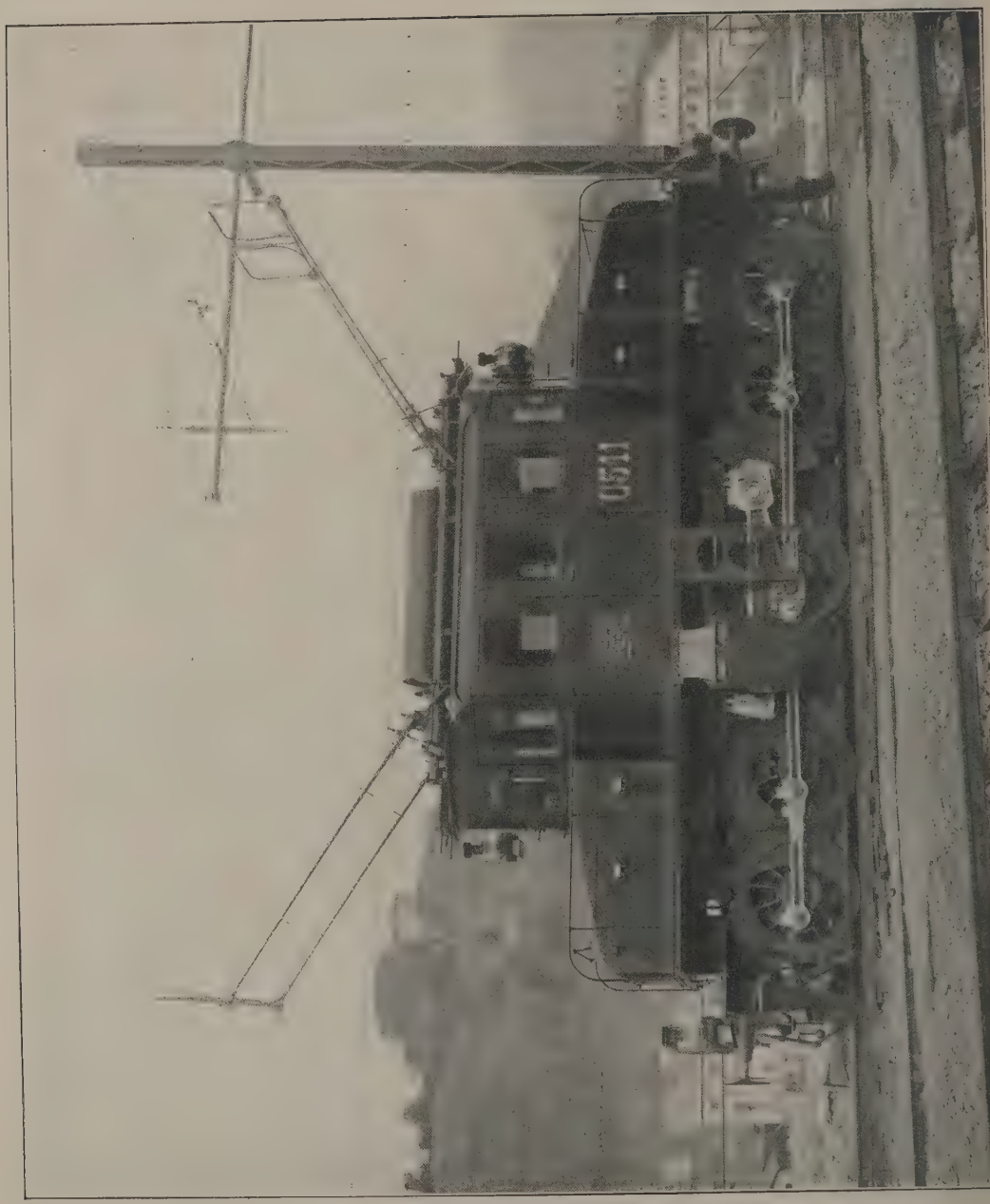


Fig. 6 — Switchboard.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The energy required for the compressor was obtained by a benzene motor coupled to a 50-kilowatt electric generator installed in a car on the special train.

This generating set was used to supply the motor driving a Reawell compressor which was used for fitting the electric connections to the rails.

III

Locomotives.

There are twenty-five electric locomotives, each having five coupled axles and wheels 1·070 metres (3 ft. 6 1/8 in.) in diameter; the leading and trailing axles have lateral play in order to enable the locomotives to run round curves of small radius. The locomotives run equally well in both directions.

The total weight of each in running order is 60 tons, but each locomotive is arranged for the addition of ballast to enable the weight to be increased to a total of 75 tons maximum, if required, in order to enable the total tractive power to be utilized of which the locomotives are capable.

Each locomotive is fitted with two asynchronous three-phase 8-pole high-voltage motors; the normal speeds of the locomotive are 22·5 and 45 kilometres (14 and 28 miles) per hour; the speeds depend on whether the motors are coupled in series or parallel. Under normal conditions the two motors are coupled in series at starting and in parallel at working speed. Coupling in series is also used when running down from Busalla to Pontedecimo as an extra safeguard.

Transmission of the rotating movement of the motors to the axles is effected by means of coupling rods and cranks.

The controlling gear can be operated equally well from each end of the driver's cab. All the high-tension conductors, with the exception of those which are placed on the roof of the cab, are enclosed in metallic casings directly connected with the rails. All the high-tension apparatus requiring frequent inspection is fitted in metal cupboards which remain open while the key is in the lock. This key, of which there is only one for all the pieces of apparatus, is connected with the gear controlling the collector bows in such manner that it cannot be used except when all the bows are lowered, and, on the other hand, the bows cannot be raised until the key has been returned to its place. Each locomotive, in addition to the ordinary accessories (brake, sanding gear, whistle, ammeter, voltmeter, etc., and safety appliances), is fitted with two motor compressors supplied by two oil-bath transformers stepping down from 3,000 to 100 volts; these motor-compressor sets can be operated automatically or by hand; a fluid resistance is also fitted for starting and for adjusting the load, and a double-bow system of current collector is used which works equally well in each direction of running without being specially operated for the purpose.

All the controlling gear of the locomotive is operated by compressed air and alternating current with relays shunted by means of a transformer from the supply line.

This system is based on the principle of avoiding all chance of contact of any member of the staff with the high-tension appliances. As has been already stated, this operation is performed by means of compressed air which acts on master controllers operating the various gear details (bows, switches, controllers, resistances); by this means much less muscular effort is required of the staff while at the same time their safety is assured.

Electric control is employed for regul-

*

ating the admission of the compressed air to the various pipes; this is done by means of relays fitted in the low-tension circuits and connected to the two master controllers operated by the driver from either end of his cab.

This arrangement has enabled the number of compressed-air pipes to be considerably reduced by means of a direct pneumatic control similar to that used on the Valteline line, and at the same time enables greater rapidity to be obtained in transmission of the control, the order of succession being automatic and saving work for the driver.

In the case of three-phase electric traction, owing to the fact that the starting is performed with a constant current and the running performed at nearly constant working speeds even under very variable loads, it is possible to use double traction without special appliances for ensuring the simultaneous working of the two locomotives with a view to nearly equal distribution of power between the two. The differences in diameter of the wheels of the two locomotives, which might appreciably modify the theoretical distribution of the load, have no influence owing to the arrangement adopted which consists in inserting in the rotors of the motors resistances which remain in circuit after the motors have attained the working speed, without producing any appreciable influence on the efficiency of the system as a whole. The compressed-air control system ensures the exact distribution of load between the motors in the case when it is required to connect them electrically on the multiple-unit system which has been adopted in many of the applications of electric traction by automotor vehicles.

The trials which have been made on the Valteline and the Giovi lines with these new locomotives have shown that they are capable of starting easily and speedily even on the heaviest gradients, and that they are capable of developing a power of 2,000 horse-power for a period not exceeding one hour

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